Present state of long-lengths of MgB_2 superconducting tapes for DC and AC applications

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Organization:

LAMIA lab. of INFM
a) Develops the technology
b) Characterize and qualify short conductors

COLUMBUS SUPERCONDUCTORS

Columbus Superconductors industrializes the techniques and commercializes MgB_2

Ansaldo Superconduttori qualifies long lengths and windings manufactured by Columbus Superconductors

Founded in February 2003
President : Manuela ARATA (INFM Pres.)
Exec. Dir.: Davide MALACALZA (Ansaldo Supercond. Pres.)

MgB_2 conductor optimization

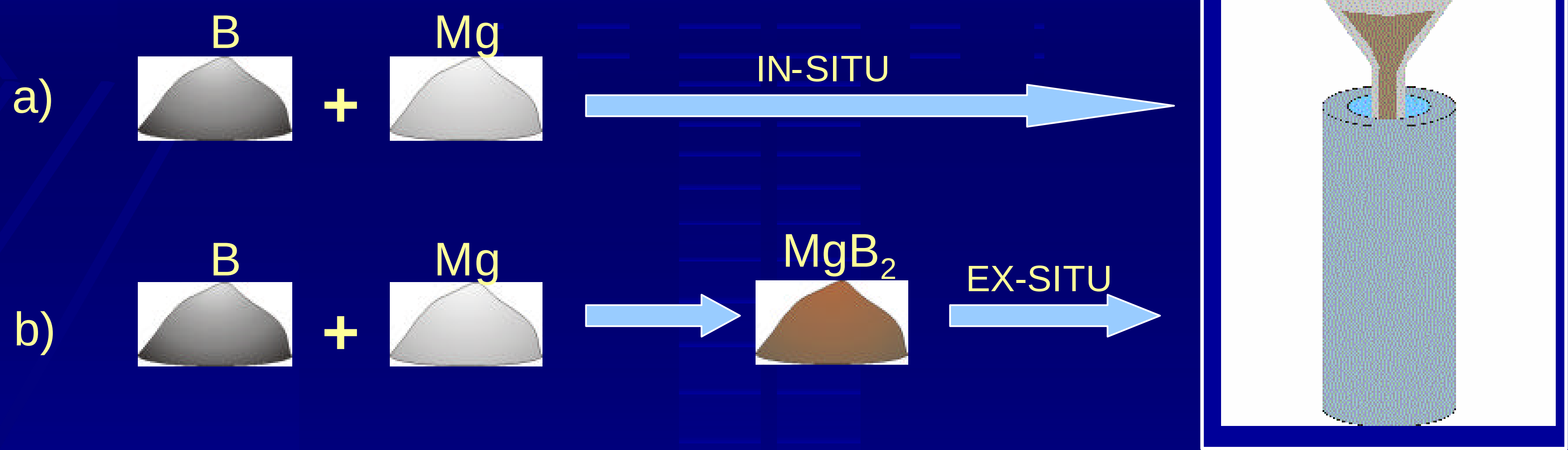
x, l

- Powder density
- Grain size
- Nano-particles inclusion
- Lattice disorder
- Critical temperature
- Doping
- Texture?
- ….

$J_c(T)$

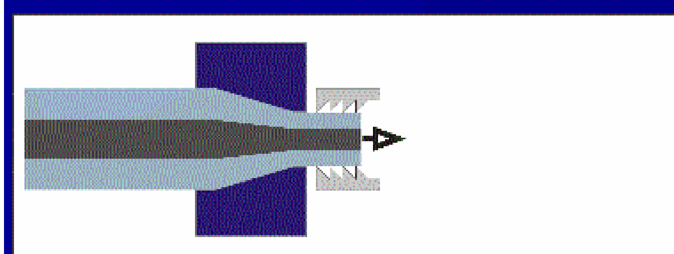
H_{irr},$H_{c2}(T)$

PIT Processing routes for the fabrication of MgB_2 wires

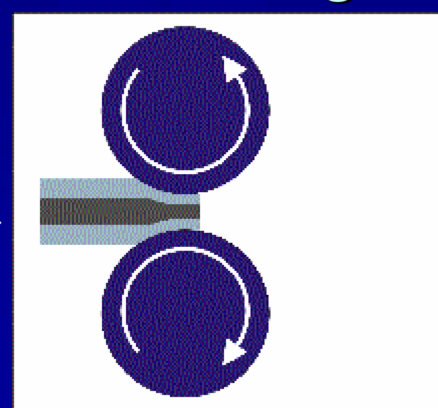


tube filling

Cold Working



wire drawing



wire rolling

long lengths of tape

Sheath material choice

- Cu,Ag,Ni heavily react with Mg above ~700°C
- Ni reacts appreciably with MgB_2 above 800°C
- Fe partly reacts with B
- Nb, Ta are virtually inert but probably too expensive

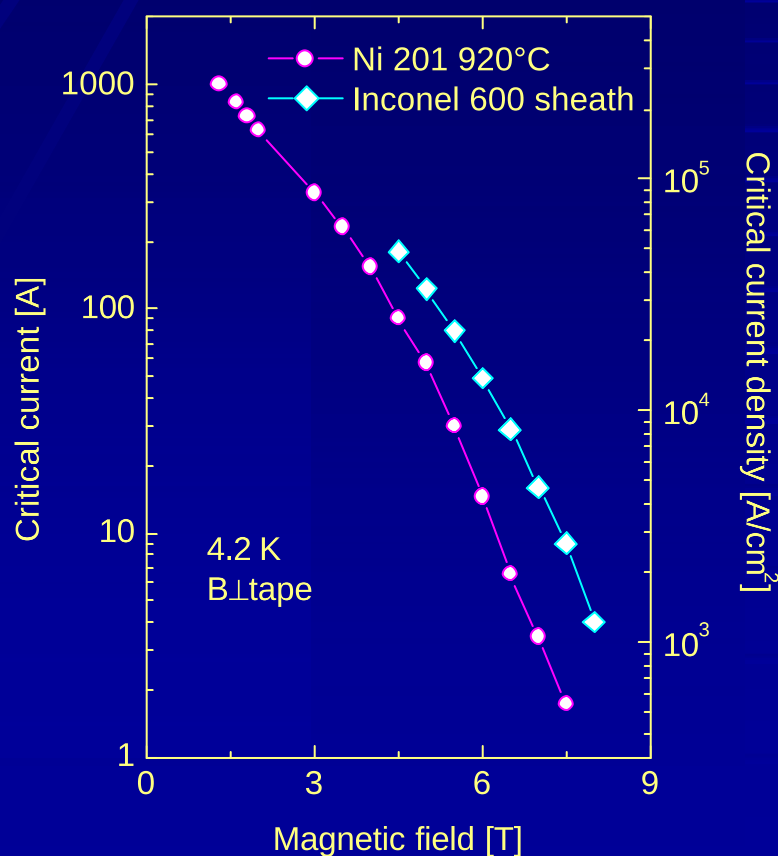
Lowering the heat treatment temperature and reducing the reaction time is preferable to be less sensitive to sheath choice both for in-situ and ex-situ wires

Ex-situ processing route -I

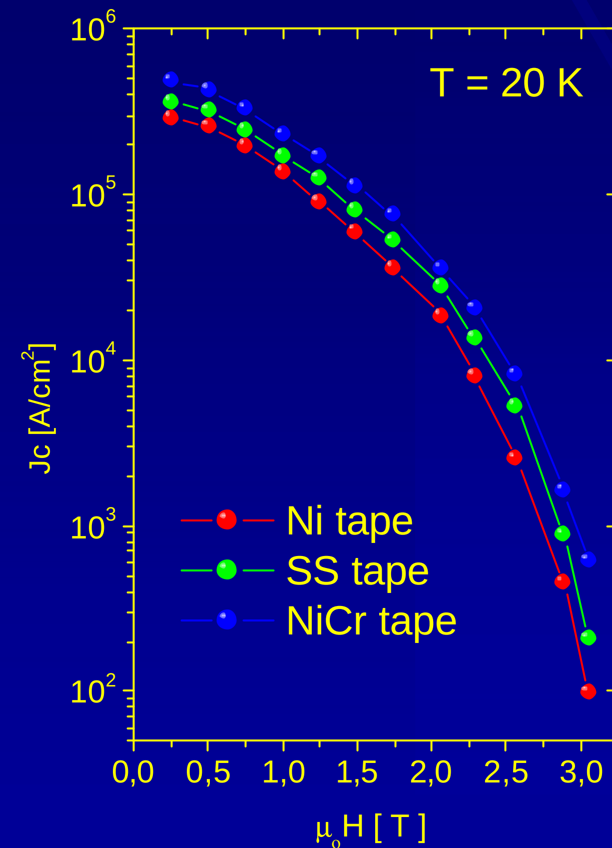
- Powder density and sausaging are the main parameters to be controlled during mechanical deformation
- Only starting MgB_2 powders need some optimization
- Sheath material has to be hard to increase MgB_2 density during cold working
- High superconducting filling factors are difficult

Ex-situ processing route -II

Reinforced conductors can be manufactured with SS, Inconel 600, NiCr alloys even with some beneficial effect

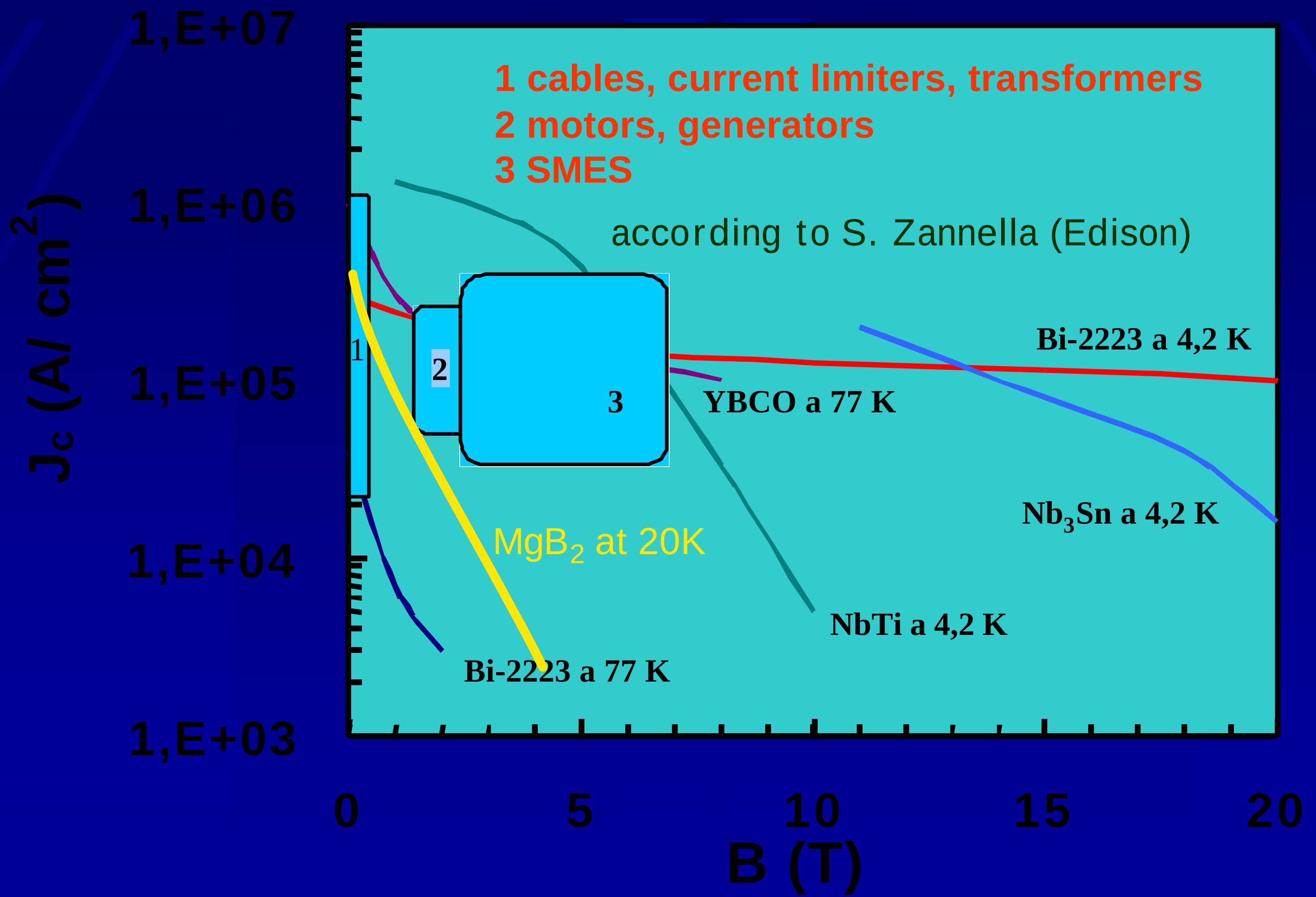


Transport I_c at 4.2K



Magnetic I_c at 20K

Where does the actual properties of MgB_2 tapes at 20K stand?



Available MgB_2 tapes at 20K meet some of the AC requirements

MgB_2 conductors developed for DC and AC applications

- DC applications (low-field MRI):

low-cost mono & multi wire & tape

- Ex-situ Ni and Ni-alloy sheathed
- In-situ Cu-sheathed

- AC applications:

Multifilamentary wire & tape

- Ex-situ Ni-alloy sheathed
- In-situ Cu-sheathed

- SFCL application:

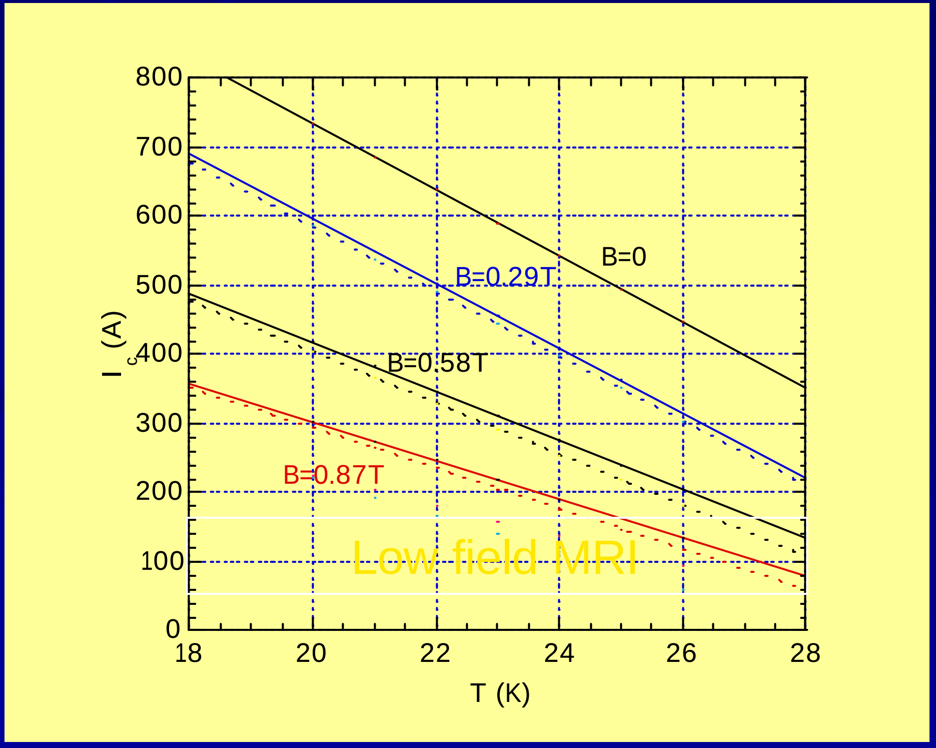
High resistance multifil. tape

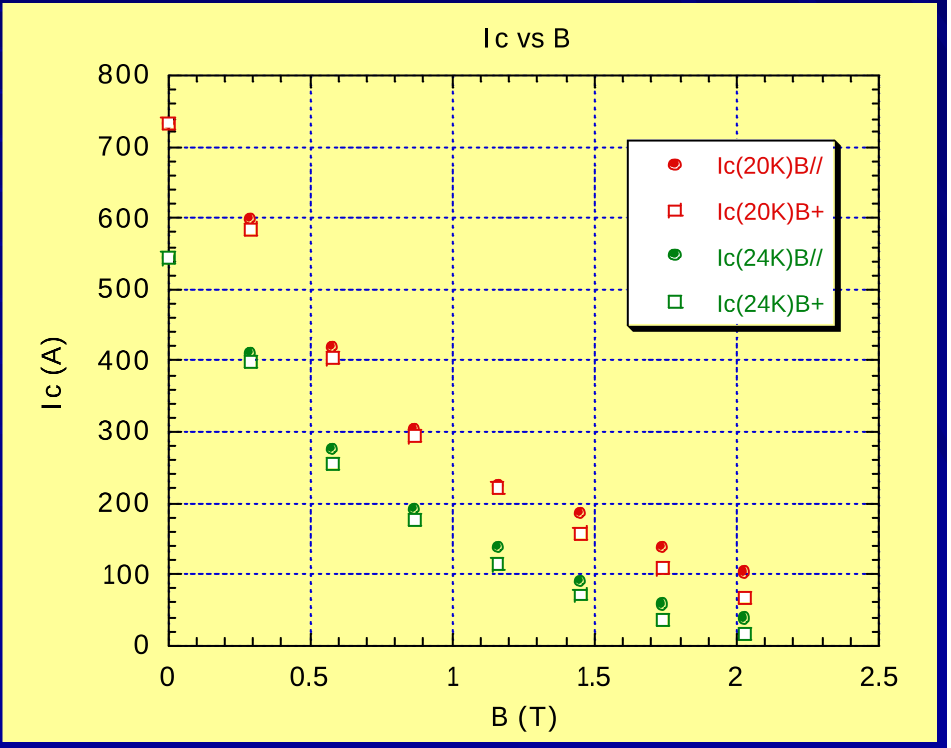
- Ex-situ very high resistance Ni-alloy with outer SS

In all cases materials target cost below 1 €/m!

20-30K properties are crucial for MgB_2 applications

Critical current of short samples cut from 200-m long conductors

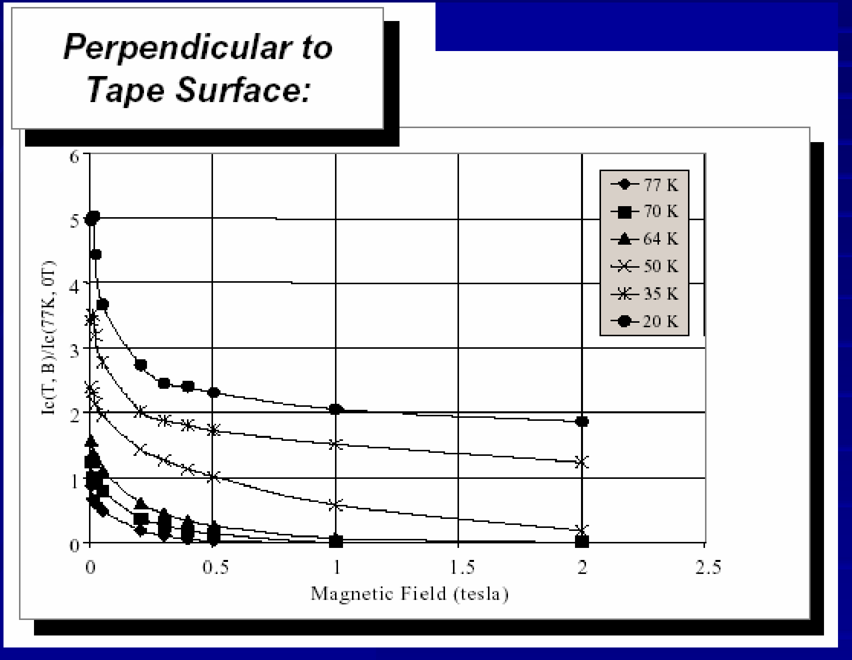




Present goal for low-field MRI is a conductor with I_c=200A at 20K, 1T for operation below 100 A

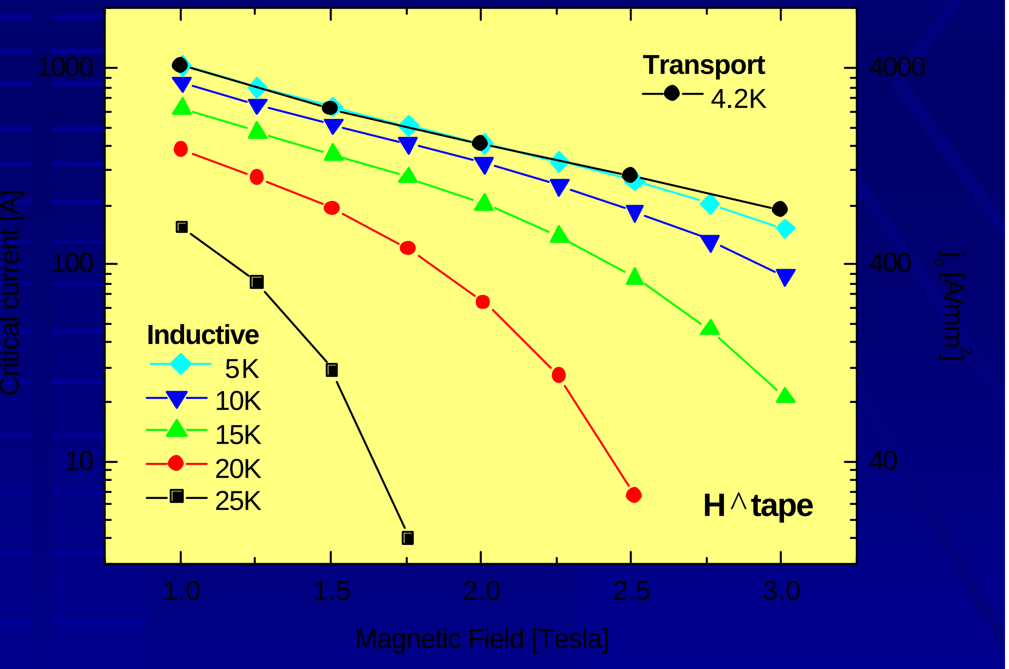
Comparison BSCCO (ASC) with MgB_2 (Columbus)

Best BSCCO conductor



With I_c^{77K} = 125 A

Standard MgB_2 (not best!)



20 K, 1T → 250 A

20K, 2T → 200 A

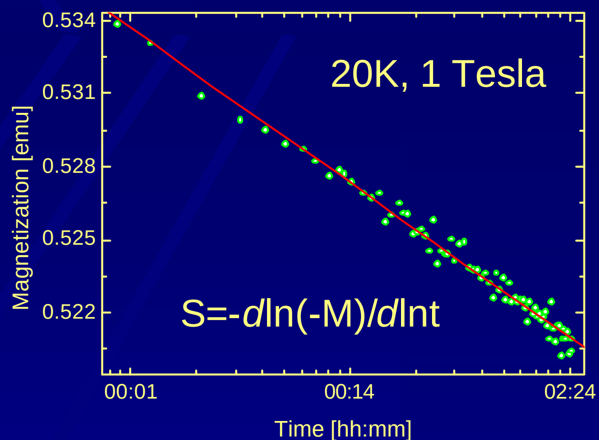
20 K, 1T → 400 A

20K, 1.5 T → 210 A

20K, 2T → 90 A

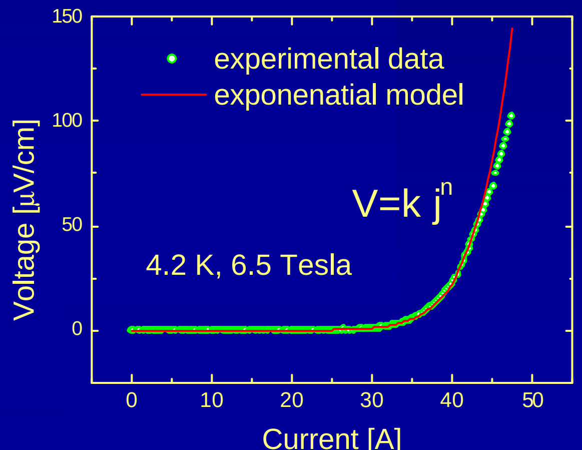
Is persistent mode operation of magnets feasible for MgB_2?

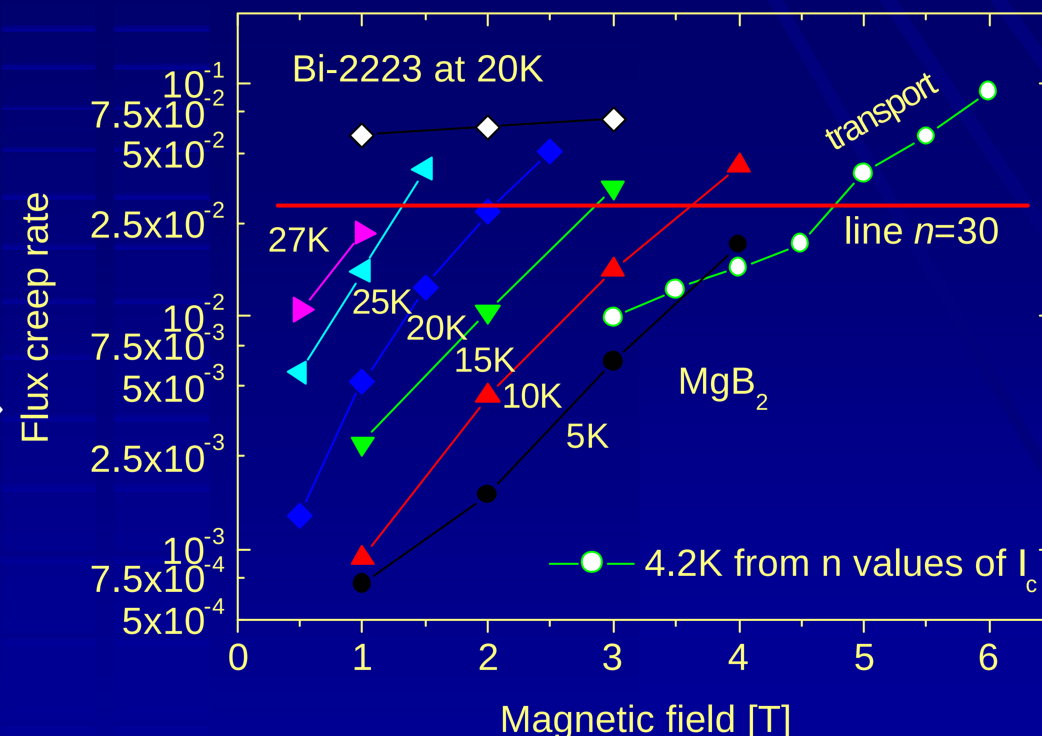
Magnetization time decay



S=1/n

Voltage-current characteristics



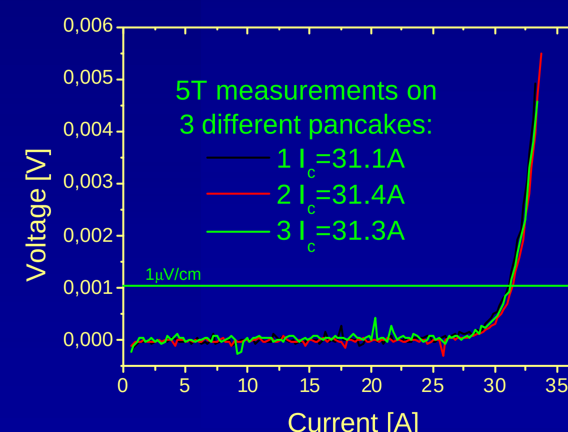


YES! Unlike HTS, MgB_2 can be operated in persistent mode!

Long lengths of MgB_2 conductor-I

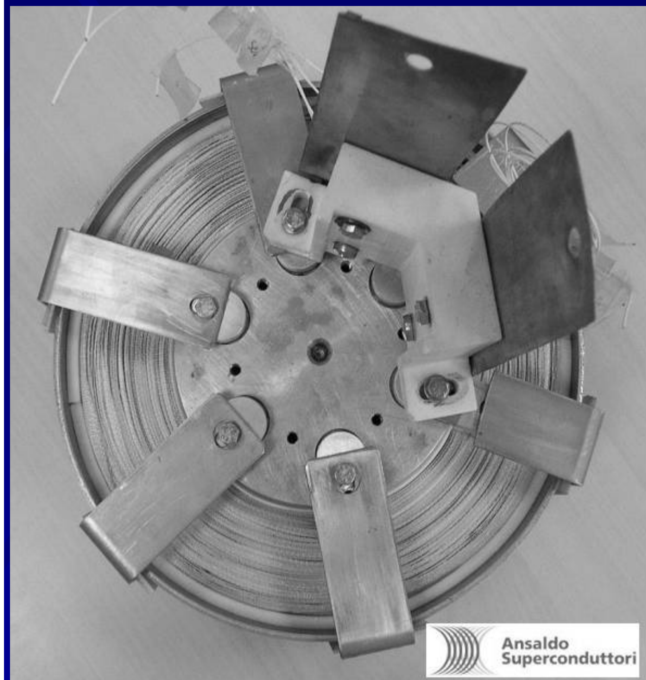
- *Ex-situ* conductors have been easily scaled to long lengths

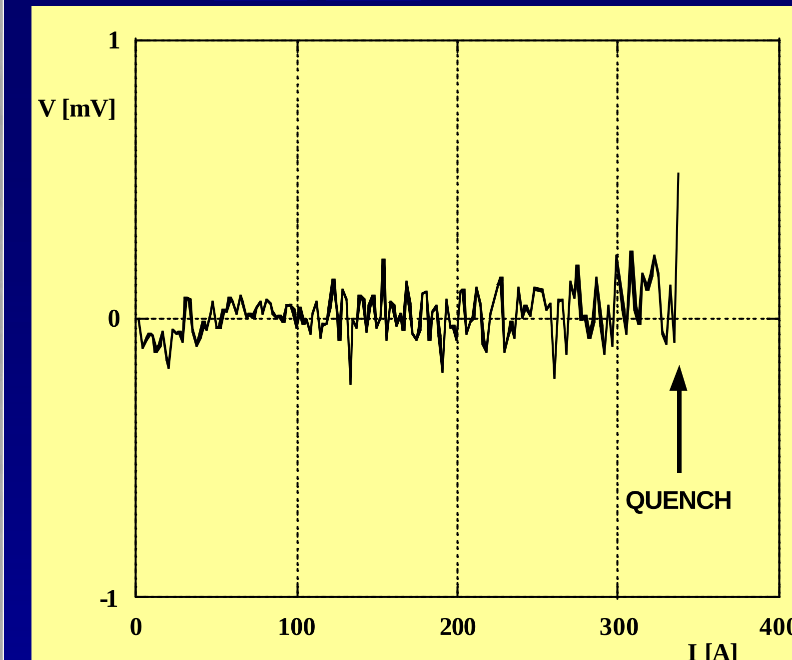
Batches up to 200 m in length have been successfully manufactured with negligible critical current reduction if sampled by short pieces



Long lengths scaling up of MgB_2 tapes successfully demonstrated

Long lengths of MgB_2 conductor-II

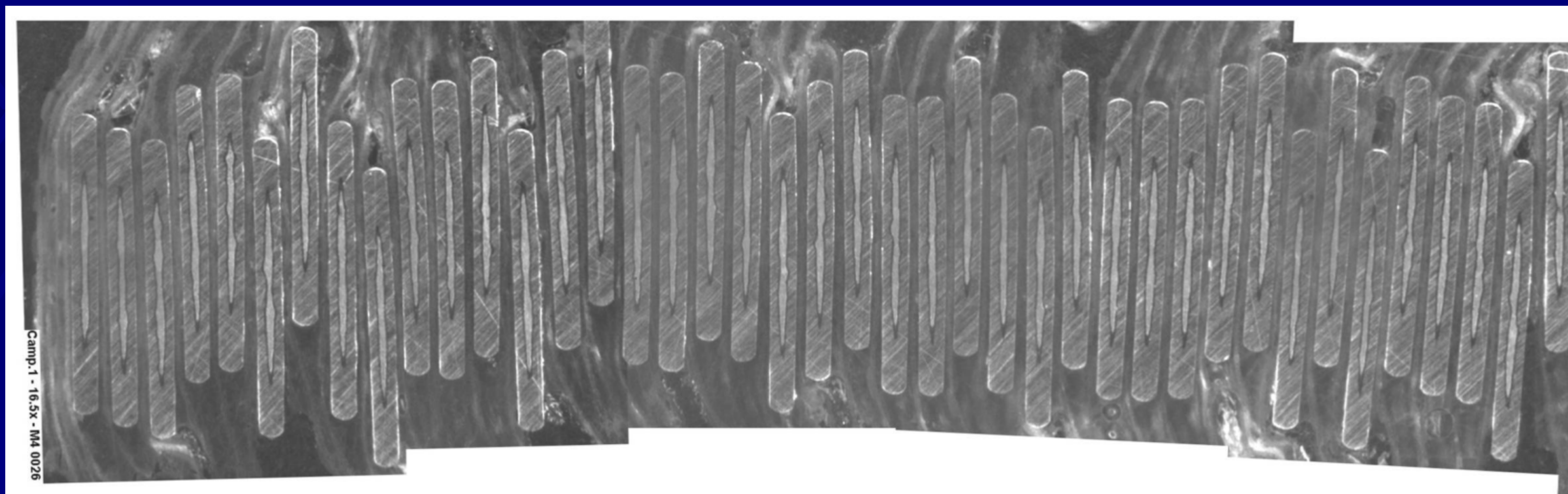


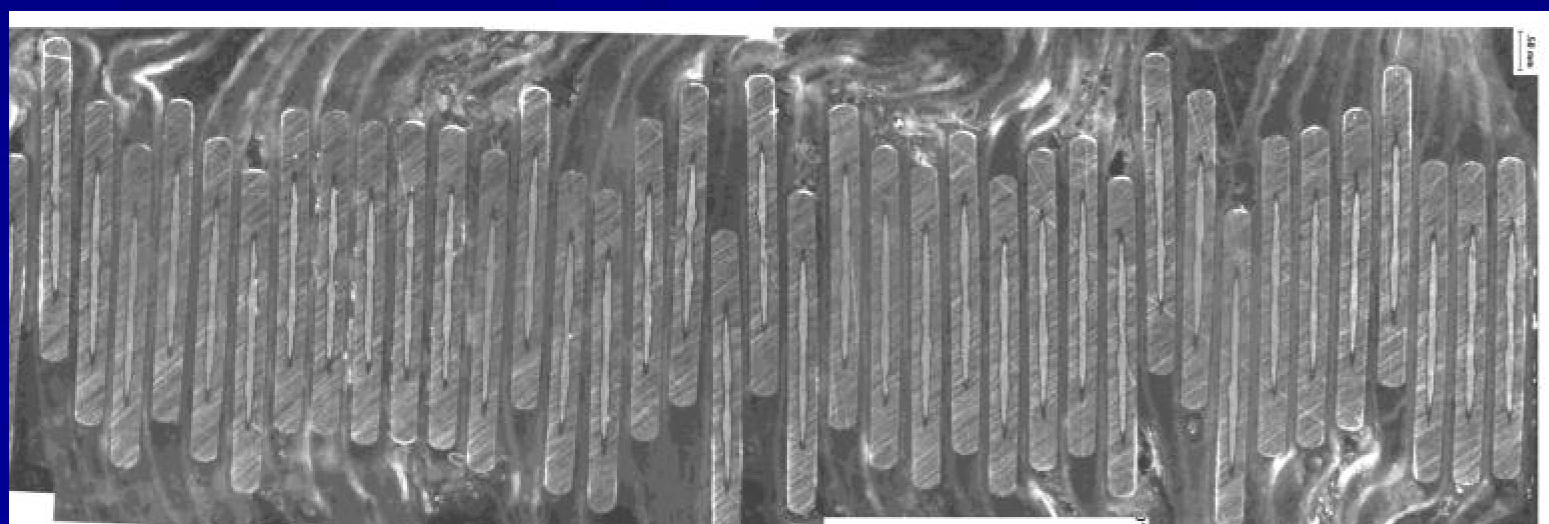


V-I curve of 100-m react&wind pancake generating a field of about 0.8 Tesla at 4.2K

Pancakes wound with 50-100 m. long monocore tapes show 50% of short length I_c

Long lengths of MgB_2 conductor-III



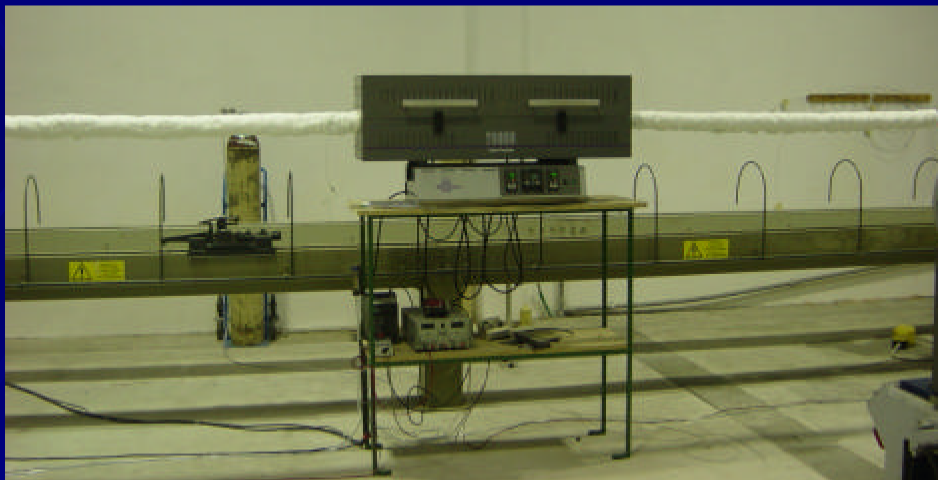


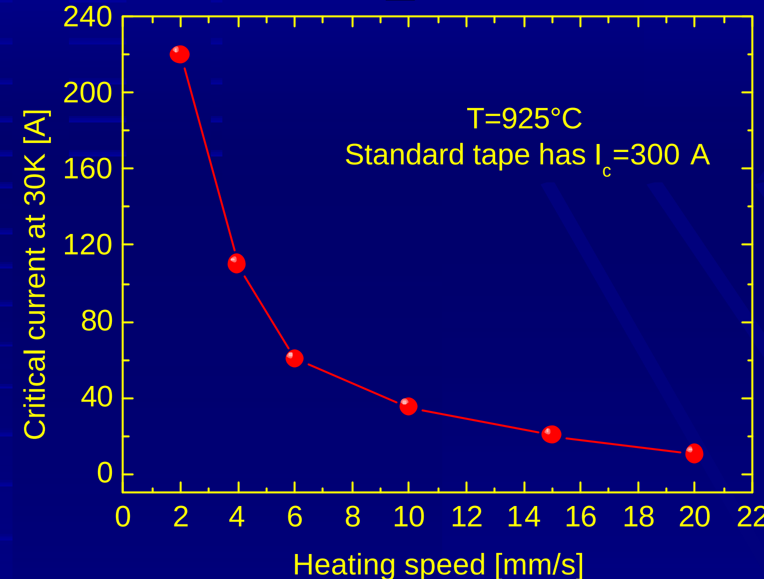
Cross section fluctuations by 30% could justify lower I_c in windings

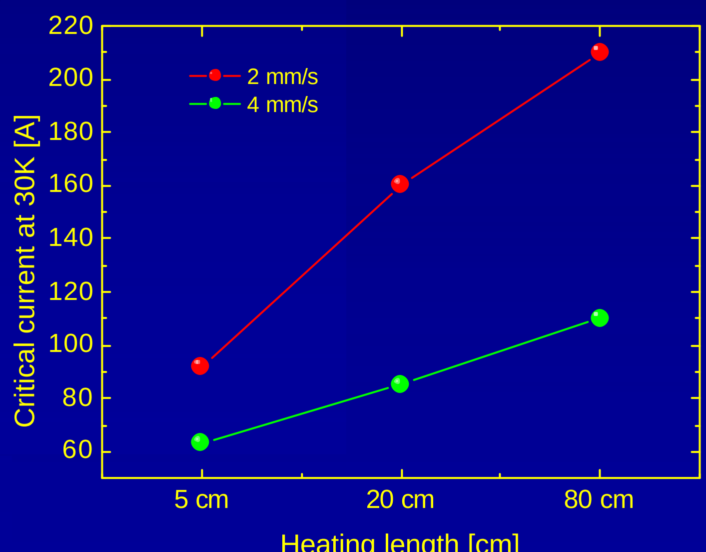
To reduce and monitor I_c scattering

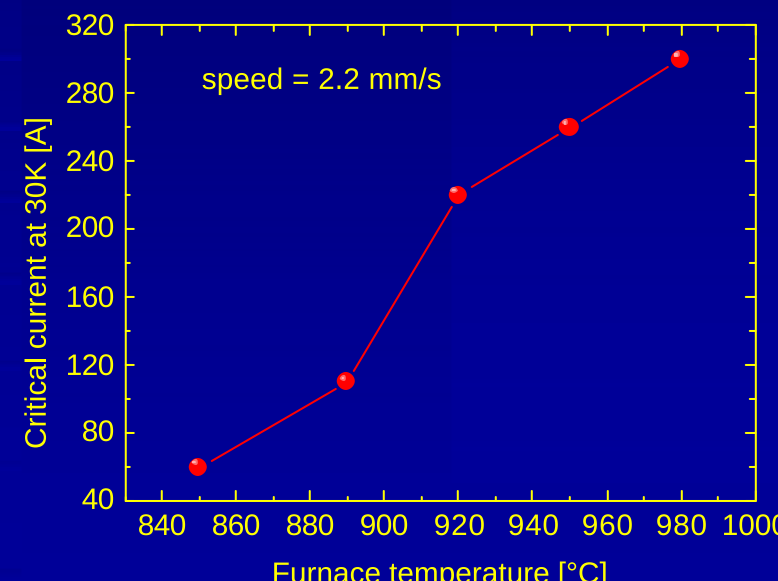
- In-line heat treatment;
- Drawing force measurement;
- Inductive determination of ferromagnetic matrix proportion

In-line heat treatment of MgB_2 tapes



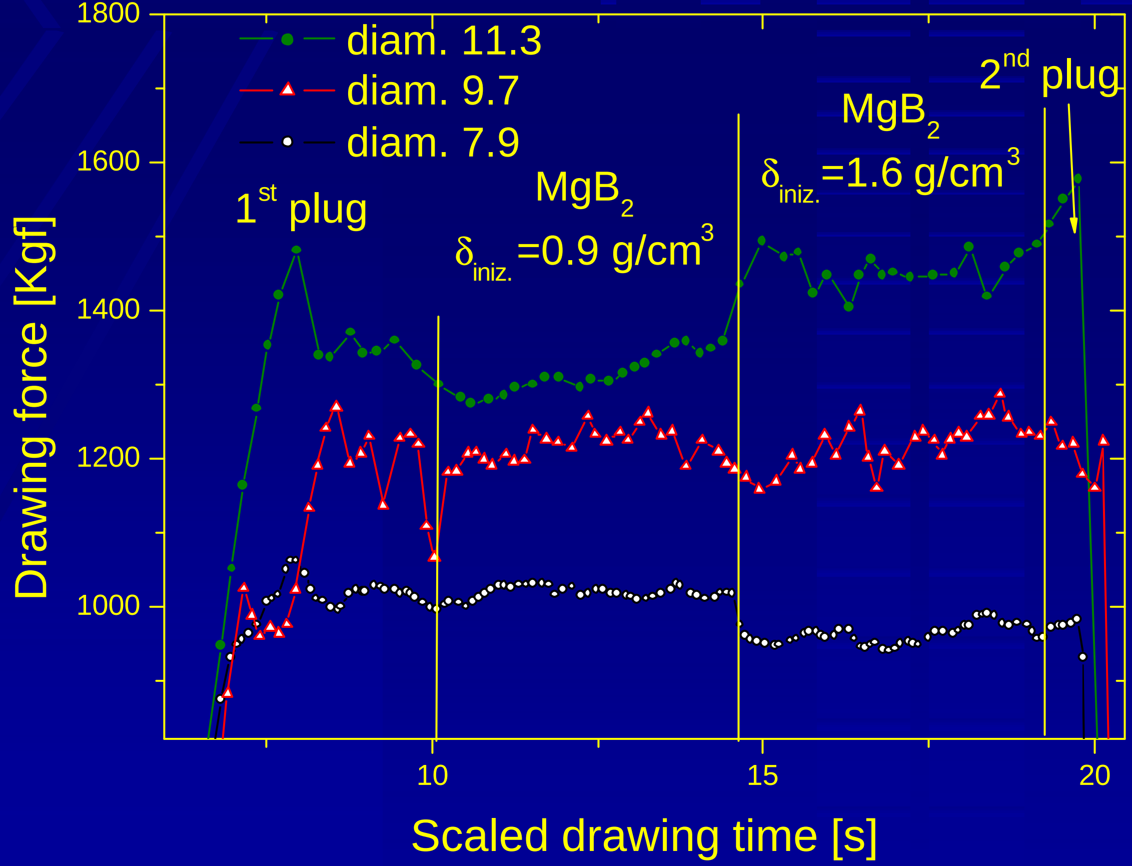






In-line heat treatment allows for more homogeneous and reliable heat treatment

Wire drawing force measurement

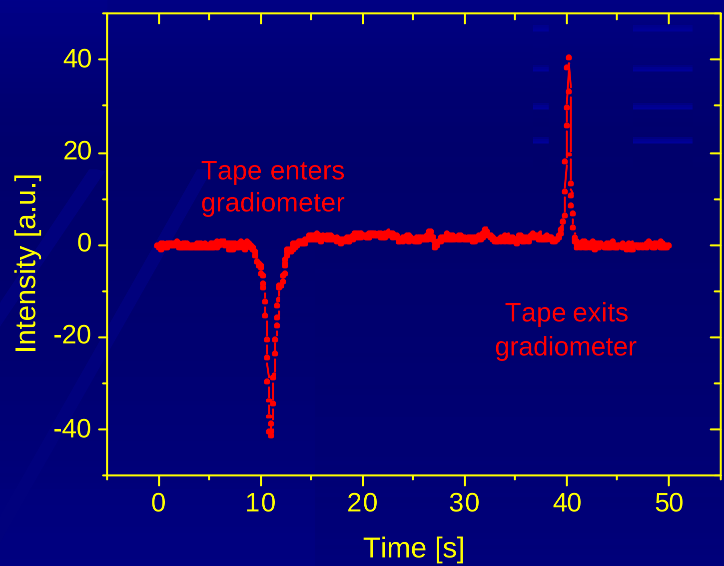


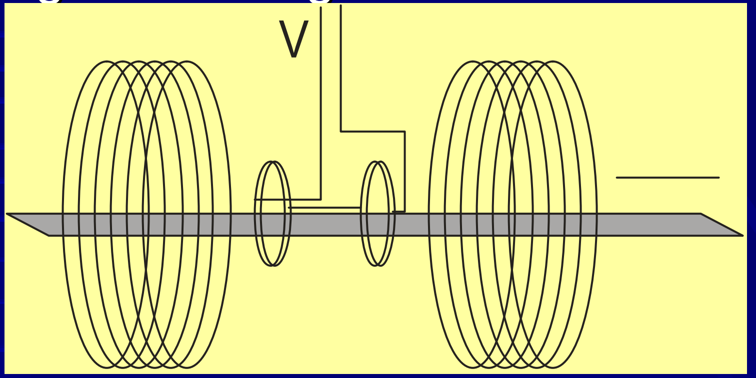
From wire drawing force profiles, inhomogeneity of the wire can be sorted out

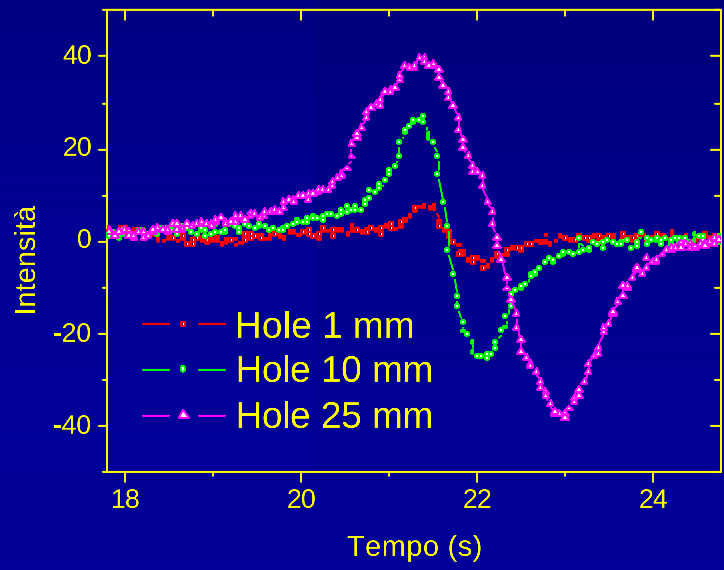
Drawing at 5 cm/s and sampling force at 10 Hz -> 1 pt. every 5 mm of wire

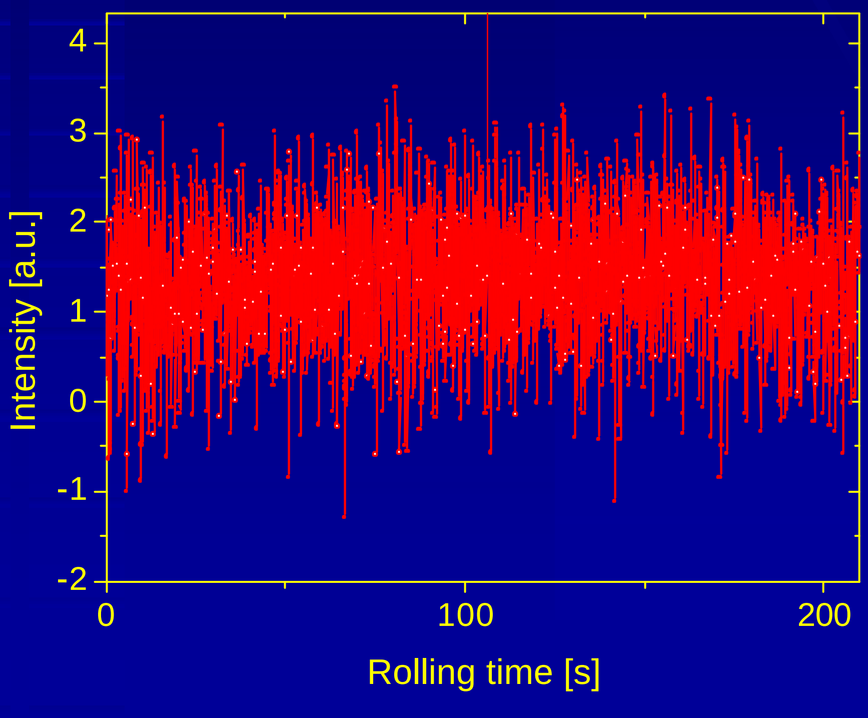
Inductive determination of ferromagnetic matrix proportion

- 1^{st} order gradiometer is placed in-line during wire rolling









The system is capable of determining local fluctuations of the sheath material proportion

The solution to critical current fluctuations are multifilamentary tapes

↓

Commercial powders have too big agglomerates > 100 μm

↓

Very fine and homogeneous MgB_2 powders have to be developed

μm-size powders are fabricated from
- Nanosized MgH_2
- μm-size amorphous Boron

↓

Mixed and reacted at 900°C for 2h in sealed Fe-Nb crucible

↓

Fine MgB_2 powders are achieved without agglomerates

↓

Long lengths: $J_c(30K) \sim 10^5$ A/cm^2

Pancakes based on this conductor show almost same I_c than short lengths

AC losses problem can be addressed in many ways

- Highly resistive matrix can be inserted straightforwardly
- Twisting and electrical (magnetical?) decoupling of filaments feasible
- Ferromagnetism of sheath material can be overcome (NiCr alloys, Cu, etc.)

Next Future

- Scaling-up to km-long MgB_2 multifilamentary tape within 6 months
- Supplying of 15 km of MgB_2 tape for prototype full scale magnet within 12 months
- Development of low-losses SFCL MgB_2 conductor with highly resistive matrix within 6 months
- Improvement of high field performance by SiC nanoparticle doping

Conclusions & future trends

- Present conductors already have a potential for application and therefore long lengths scaling up is already requested
- Collecting all ideas in one conductor should lead to a remarkable progress
- Nanoparticles addition, ultrafast reaction to reduce grains size, heavy ball milling are preferable techniques to increase performance because they should not affect T_c dramatically
- AC applications should be greatly enabled by the ongoing multifilamentary conductor development