The European industrial status on superconductor manufacturing Discussion

A. Ballarino

13/09/2022

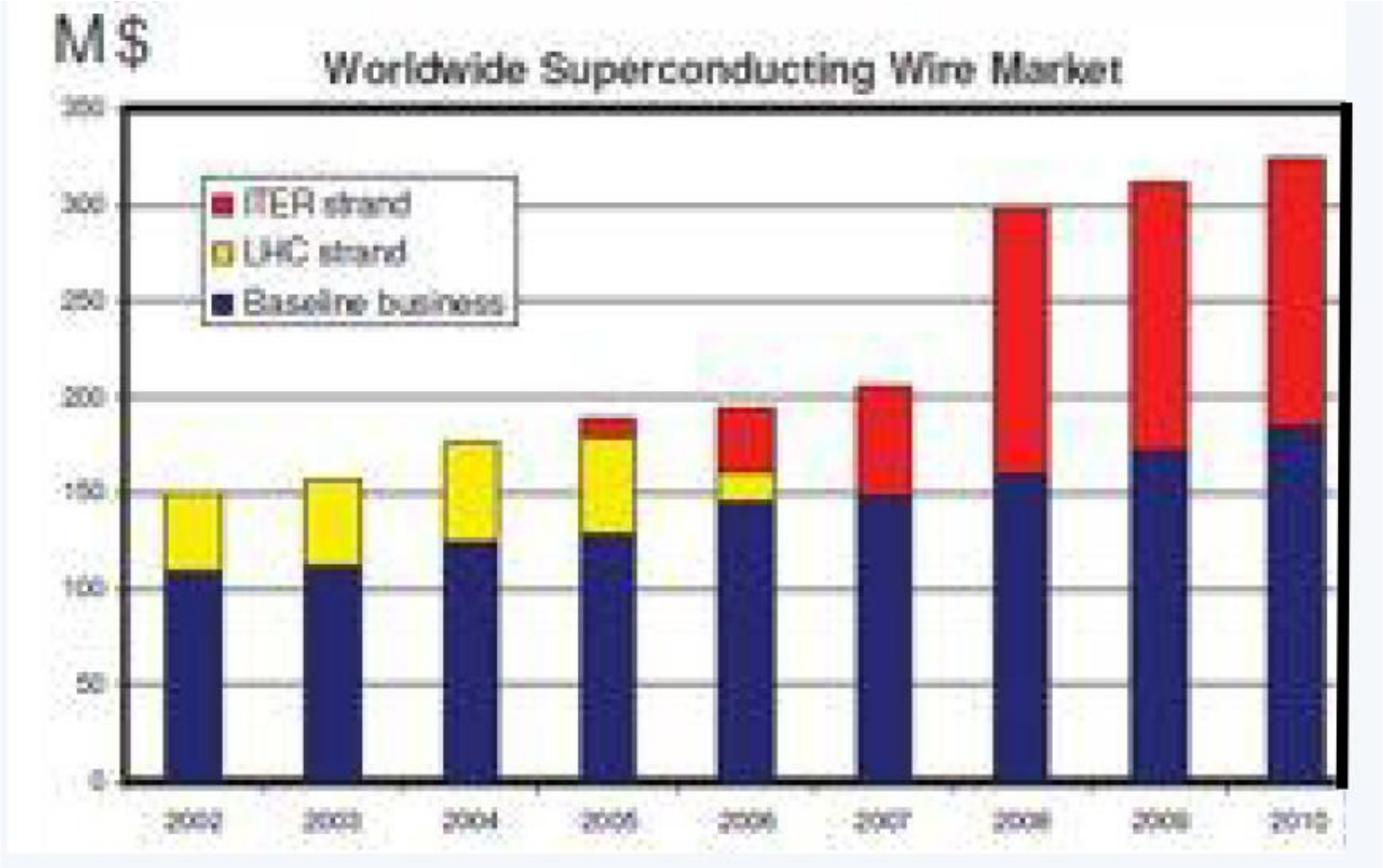
Industrial production of Nb-Ti wire

- The **global market** is dominated by the requests for **Magnetic Resonance Imaging (MRI) systems** – which assure continuity and large production through the years at an affordable cost

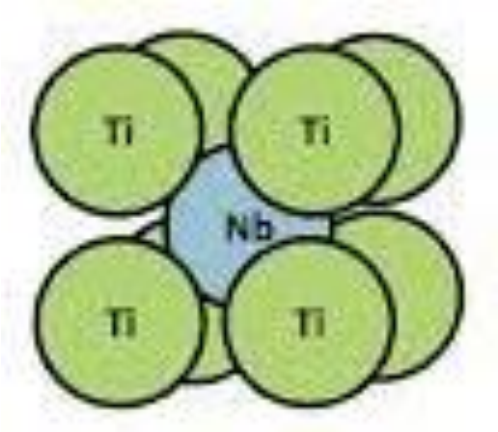
  Other large requests are for **Nuclear Magnetic Resonance** (NMR) spectroscopy, magnets for **fusion** and for **HEP** (magnets for accelerators)

- **Performance wise**, the industrial **production process is well controlled and reproducible**. Mechanism of pinning understood and implemented in large scale production. α-Ti precipitates size and density tunable via composition, cold drawing and heat treatment

Industrial production of Nb-Ti wire



Nb-Ti wire



- Body-centered cubic alloy
- Isotropic
- Tc ~ 11 K
- Bc2 ~ 13 T
- Excellent electrical and mechanical properties
- Assembled in different cable configurations
- Used in magnets up to ~ 9 T @ 4.2 K and up to ~ 10 T @ 1.9 K
- Reference cost: ~ 1 Euro/kA m*

*before the recent increase of cost of raw materials

LHC Nb-Ti conductor specification

Nb-Ti wires

Performance specification

LHC Wire

STRAND	Type 01	Type 02
Diameter (mm)	1.065	0.825
Cu/NbTi ratio	1.6-1.7 ± 0.03	1.9-2.0 ± 0.03
Filament diameter (μm)	7	6
Number of filaments	8800	6425
Jc (A/mm^2) @1.9 K	1530 @ 10 T	2100 @ 7 T
$\mu_0 M$ (mT) @1.9 K, 0.5 T	30 ±4.5	23 ±4.5

LHC Cable

CABLE	Type 01	Type 02
Number of strands	28	36
Width (mm)	15.1	15.1
Mid-thickness (mm)	1.900 ±0.006	1.480 ±0.006
Keystone angle (degrees)	1.25 ±0.05	0.90 ±0.05
Cable Ic (A) @ 1.9 K	13750 @ 10T	12960 @ 7T
Interstrand resistance (μΩ)	10-50	20-80

$\Phi < \sim 1.3$ mm (self field stability)

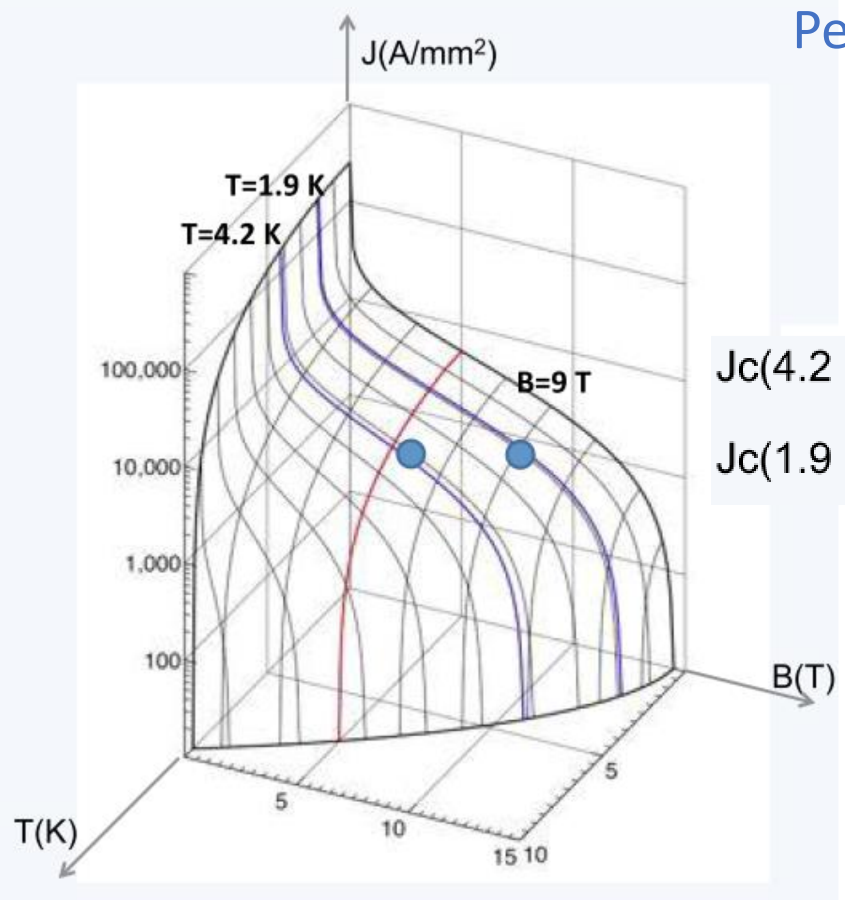
1-1.1 if other stabilizer is added

$\Phi < \sim 40$ μm (adiabatic filament stability)

It depends on layout
Hysteresis losses may need to be specified

Industrial Nb-Ti - Performance

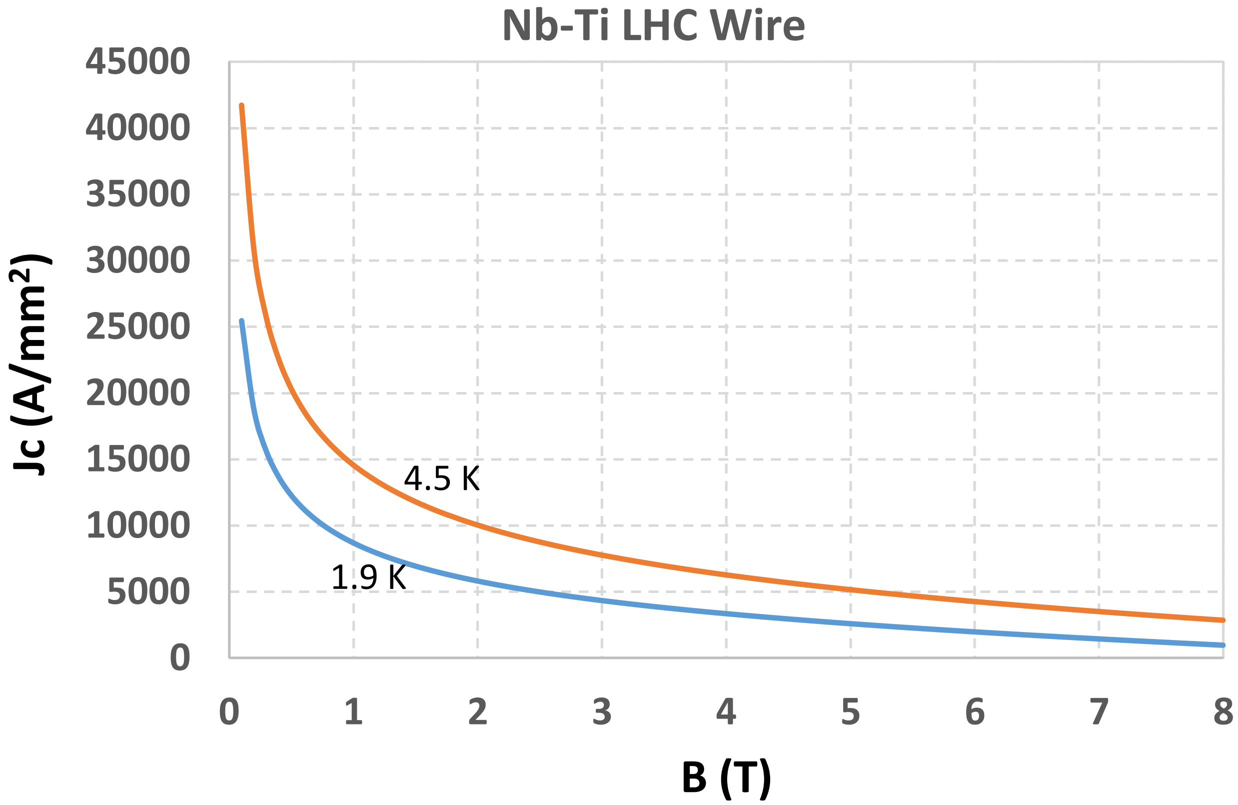
Production **in large quantity** and **long unit lengths** (several km) of high quality Nb-Ti wire. High standards of **QA**. Flexibility to adapt to **specific requests** (RRR, filaments size, filaments twisting, Cu/non Cu ratio,…)



Performance of LHC Nb-Ti wire

Jc(4.2 K, 6 T)~2300 A/mm²

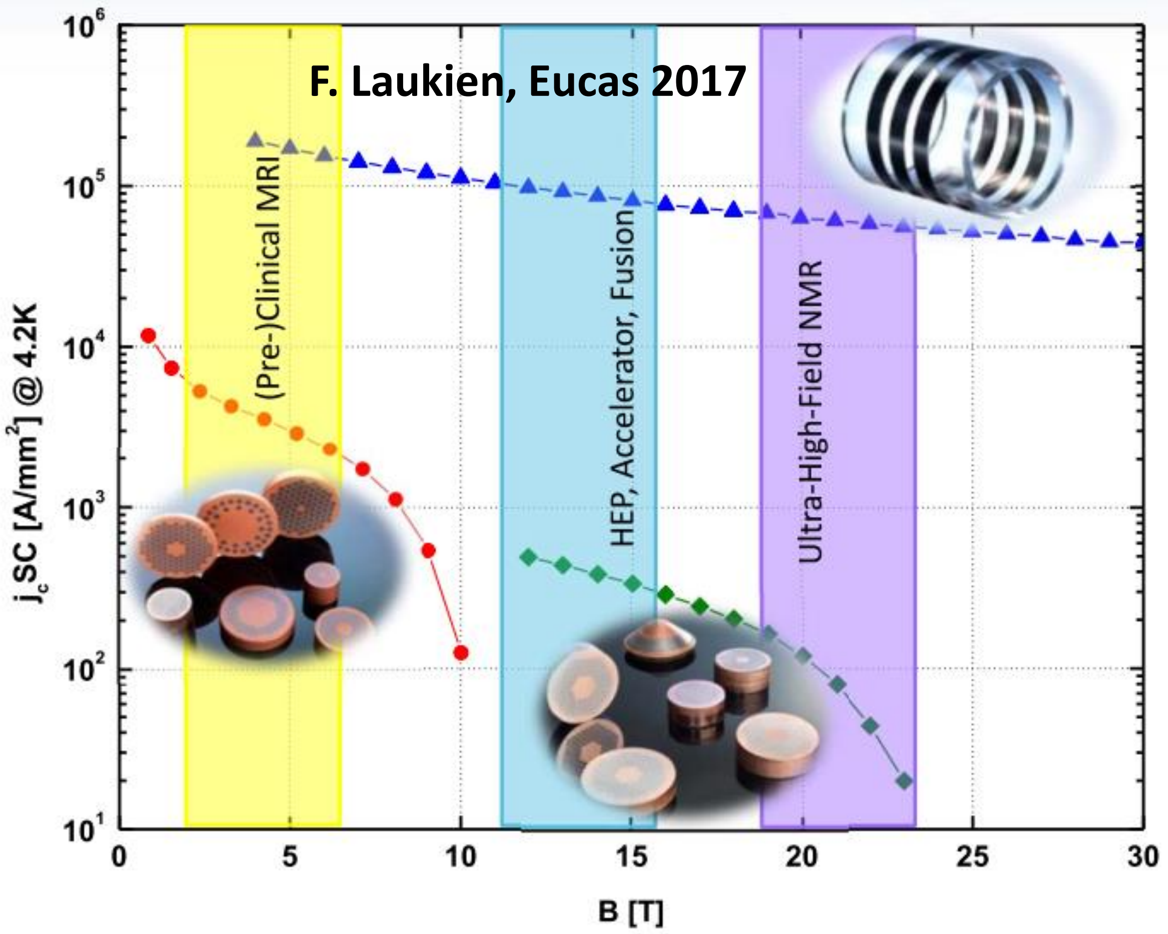
Jc(1.9 K, 9 T)~2300 A/mm²



Manufacturer of Nb-Ti Wire – Bruker

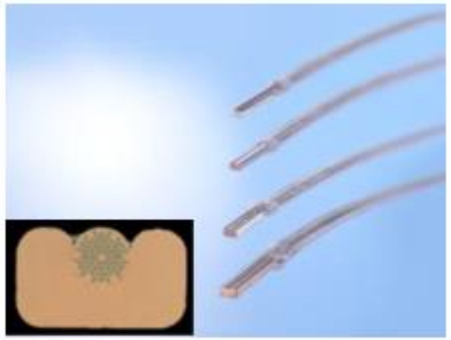
Bruker EAS/OST

- Different types of round and rectangular Nb-Ti wires, bare or insulated (braided or varnish)
- Bruker production for **LHC**: **Nb-Ti wire** for MB and MQ and for other magnets (LHC Type 5 a and Type 6 wire for insertion quadrupoles), cable for ATLAS, **BSCCO 2223 HTS** for current leads



NbTi-based

NbTi (Niobium-Titanium)



NbTi Wire in Channel (WIC)

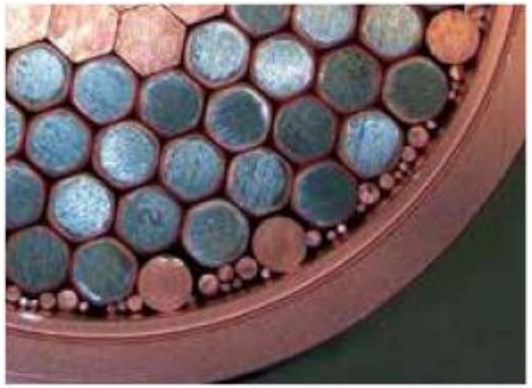
B < 9.5 T

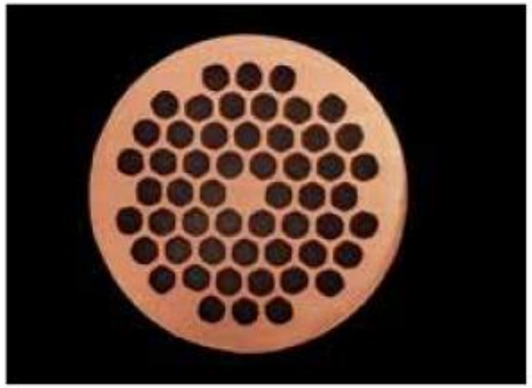
Manufacturer of Nb-Ti Wire - Luvata

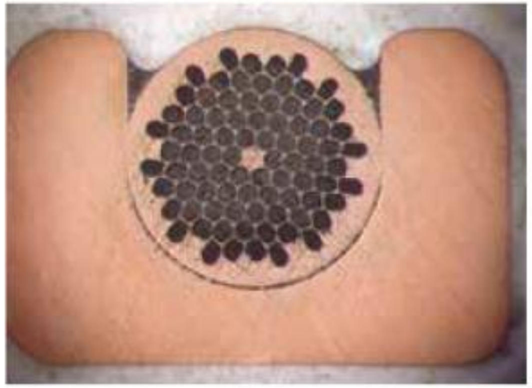
Luvata USA/Luvata Pori (EU)

- Enameled monolithic wires in round and rectangular configurations
- Wire-in-channel or cable-in-channel integrated conductors
- Luvata Pori production for **LHC**: 1/8 of MB+MQ Nb-Ti outer cables/wire

LUVATA
SPECIAL PRODUCTS
A Group Company of MITSUBISHI MATERIALS


Multifilament billet assembly


NMR/MRI wire, available also as rectangular


MRI wire-in-channel (WIC) conductor with 84 filaments


Multifilament billet assembly


Braided wire inspection

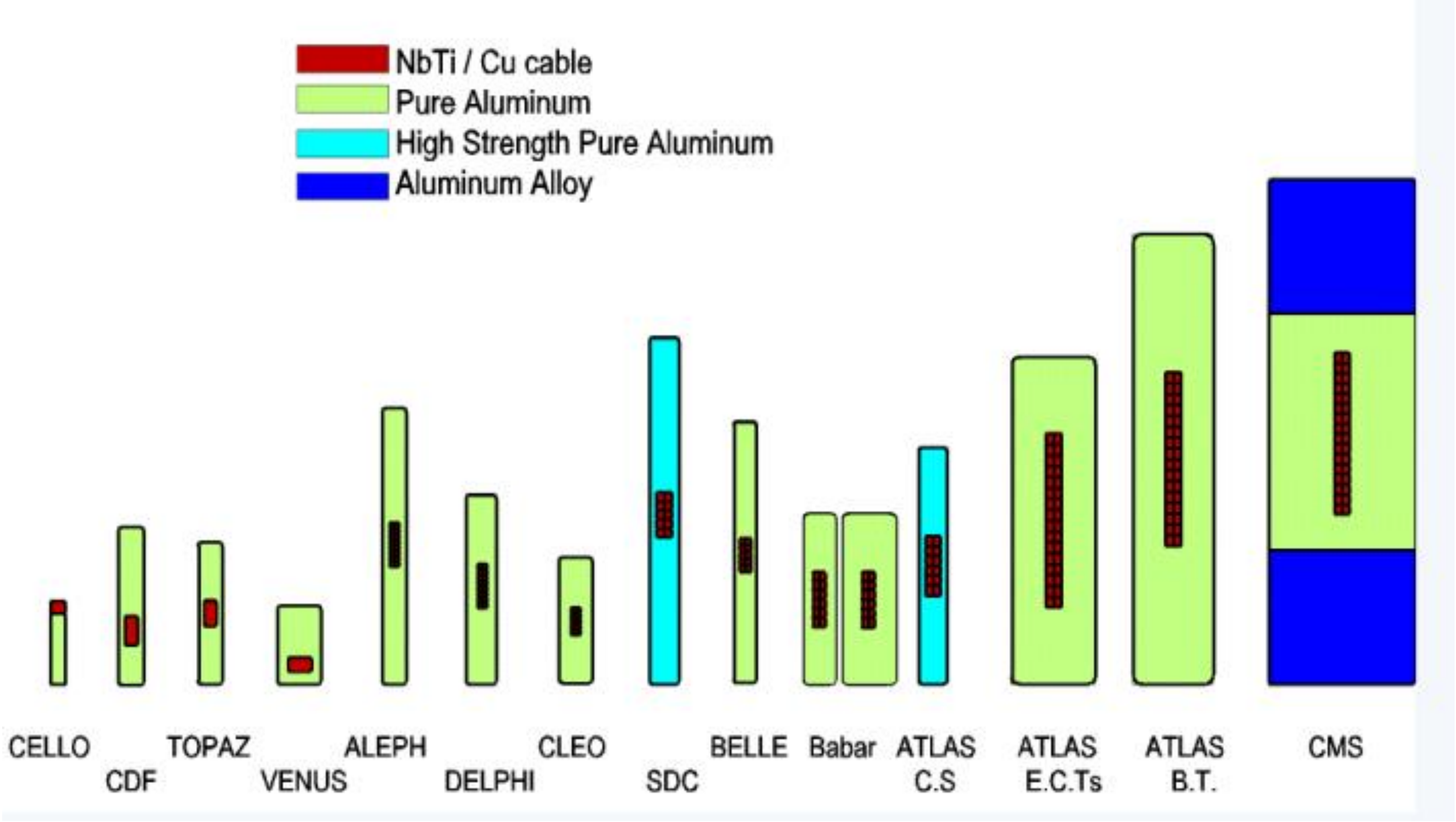

Superconductor rod production

Other non-European Manufacturers of Nb-Ti Wire

- SuperCon (USA)
- TVEL (Russia) – Production at Chepetsky Mechanical Plant (Glazov)
- KAT (Korea)
- Furukawa, Jastec, Hitachi (Japan)
- Supercon (USA)
- WST (China)

Thanks to MRI and NMR applications, Nb-Ti wire production is maintained at the industrial level

Nb-Ti Cables for detector magnets



Aluminum stabilized and mechanically reinforced Rutherford cables

Rutherford cables

Rutherford cabling machines and recent cabling activities:

- **CERN**, 40-strand, development followed by series production of: **HL-LHC Nb-Ti** cables and HL-LHC **Nb_3Sn** MQXB and 11 T Dipole Nb_3Sn cables; development and production of **Fresca 2** , **SMC**, **eRMC**, **RMM** Nb_3Sn cables. This implied upgrading/implementing QA and QC equipment/procedures. Max conductor mass: **~ 1200 kg**. Envisaged upgrade of cabling facility/infrastructure for production of cables with a larger number of strands;
- **LBNL**, 60-strand, development followed by series production of the HL-LHC **Nb_3Sn MQXA cables (and other projects).** Max conductor mass: **~ 200 kg**;
- **FNAL**, 42-strand, development and production of **11 T Dipole Nb_3Sn cables (and other projects**). Max conductor mass: **~ 200 kg**

Knowledge, development and production of Rutherford cables for accelerator magnets is presently maintained via activities at the laboratories

Rutherford cabling in industry

Rutherford cabling machines at:

- Brugg, Switzerland, 40-strand;
- Tratos cavi, Italy, > 60-strand (recent installation);
- Furukawa, Japan
- New England Wire Technology, USA, 36-strand
- ASIPP, Hefei, China

A **“sufficiently” large project** – with medium term definition of production requirements – could **attract** again **interest of industry.**
R&D on novel cables (superconductor/layout) is **more effective at the laboratory** level.
Series production (if sufficiently large) can be **industrialized.**

Concluding remarks on Nb-Ti

- Large **Nb-Ti wire production** and associated know-how and infrastructure are maintained in industry thanks to the **MRI/NMR market**
- **Performance of wire** has basically reached the physical limits of Nb-Ti – and it seems to satisfy requirements for detectors
- **Development and production** of **Rutherford cables** for accelerator technology are **today** performed at the **laboratories**. This is a critical and important activity that requires specific know how and dedicated infrastructure. A sufficiently large project could attract, again, interest of industry
- **In general**, if novel concepts/designs are needed, it is important to **elaborate technical specifications based on requirements**, **discuss variants with industry**, **foresee time and budget for <u>both</u> development and scaling-up in industry**
- There is important **know-how, in the laboratories,** associated with specific requirements of **wire and cables for accelerator magnets.** Ex. Recent effort at CERN for re-establishing, for HL-LHC, a process for the SnAg coating of the Nb-Ti wire (affecting inter-strand resistance in Rutherford cables); measurement techniques; maintenance and upgrade of infrastructure for measurements – not available in industry – both for new developments and QC purposes;…

Concluding remarks – Nb_3Sn

- Bruker and Luvata produce **Nb_3Sn wire:**

  HL-LHC performance (Jc ≥ 2450 A/mm^2 @ 4.2 K and 12 T)
  - Bruker wire: **Power in Tube** (NED, development for HL-LHC) and Internal Tin **RRP®** (Bruker OST for HL-LHC, US CDP)
  - Luvata: Internal Tin **Rod In Tube** (Internal Tin for NED, Rod in Tube R&D development with CERN for FCC)
  - Non-european industry: CERN R&D with TVEL (Russia), KEK (Jastec and Furukawa, Japan), KAT (Korea)

  ITER performance (Jc ≥ 800 A/mm^2 @ 4.2 K and 12 T)
  - Bruker wire: **Internal Tin** (Bruker OST: ~ 60 t production for ITER EU and ~ 13 tons for USIPO), **Bronze Route** (~ 40 t production of Bruker EAS for ITER)
  - Luvata US wire: **Internal Tin** for TF coils (~ 26 t for USIPO)

  For ITER, Nb_3Sn produced also by Jastec, Hitachi (Bronze Route) and Furukawa (Bronze Route) – Japan, KAT – Korea, WST – China, Chepetsky Manufacturing plant (Bronze Route) - Russia

- **Nb_3Sn** is a **complex material**: used **only when field requirements reach performance limits of Nb-Ti**