Usage of REBCO conductors Bruker Ultra-High-Field NMR program

Matteo Alessandrini
On behalf of the R&D magnets department
Bruker BioSpin

CERN - Workshop on ultra-high-field solenoids, 25.11.2025

Usage of REBCO conductors in the Bruker Ultra-High-Field NMR program

01 NMR magnets technology > *NMR Requirements & Effect of Magnetic Field*

02 NMR systems at Bruker > *Overview NMR Portfolio & status UHF program*

03 REBCO Tapes > *Maturity and gaps, referred to NMR-grade cond.*

NMR magnets technology

> Requirements & Effect of Magnetic Field

Requirements for an NMR magnet technology

NMR measurements requirements

Very high spatial homogeneity of the magnetic field in the sample space for high-resolution NMR (including RT-shims)

-> Field spatial gradient $\delta B/B \leq 1$ ppb in the sample volume (~20 mm long cylinder, ø 5 mm)

Very time-stable magnetic field (very small field drift)

-> Field temporal variation $\delta B/time \leq 10$ ppb/h (at constant drift, it means a field loss < 1% in ~ 110 years)

Product-related requirements (customer)

- **System size** required lab space and transportability
- **Cryogen consumption** during operation
- **Price** for the system, not only sale price but also the total cost of ownership

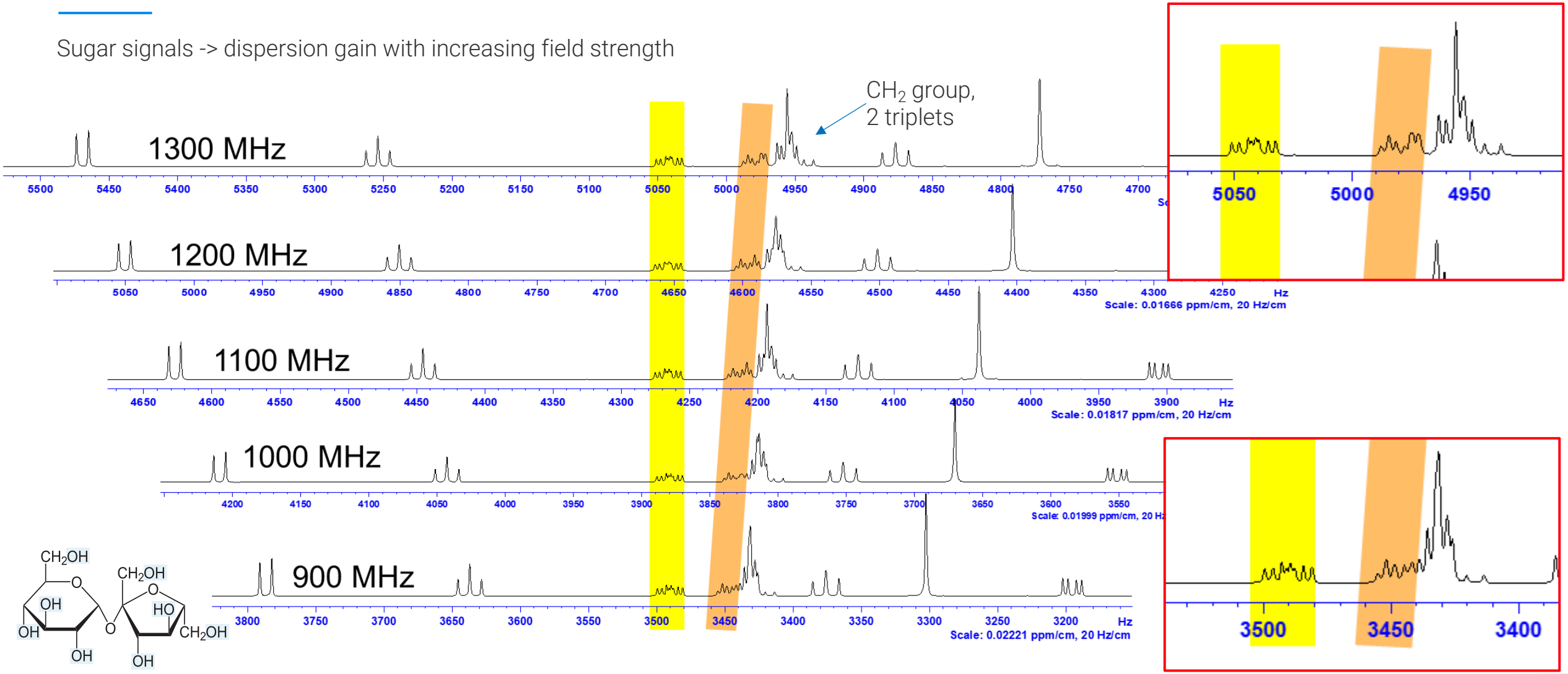
NMR quality -> need for higher magnetic fields

Higher fields allow:

- higher resolution (dispersion), i.e. better peak separation
- higher signal to noise ratio (SNR) – better acquisition of genuinely small signals

Better peak separation in the NMR spectrum

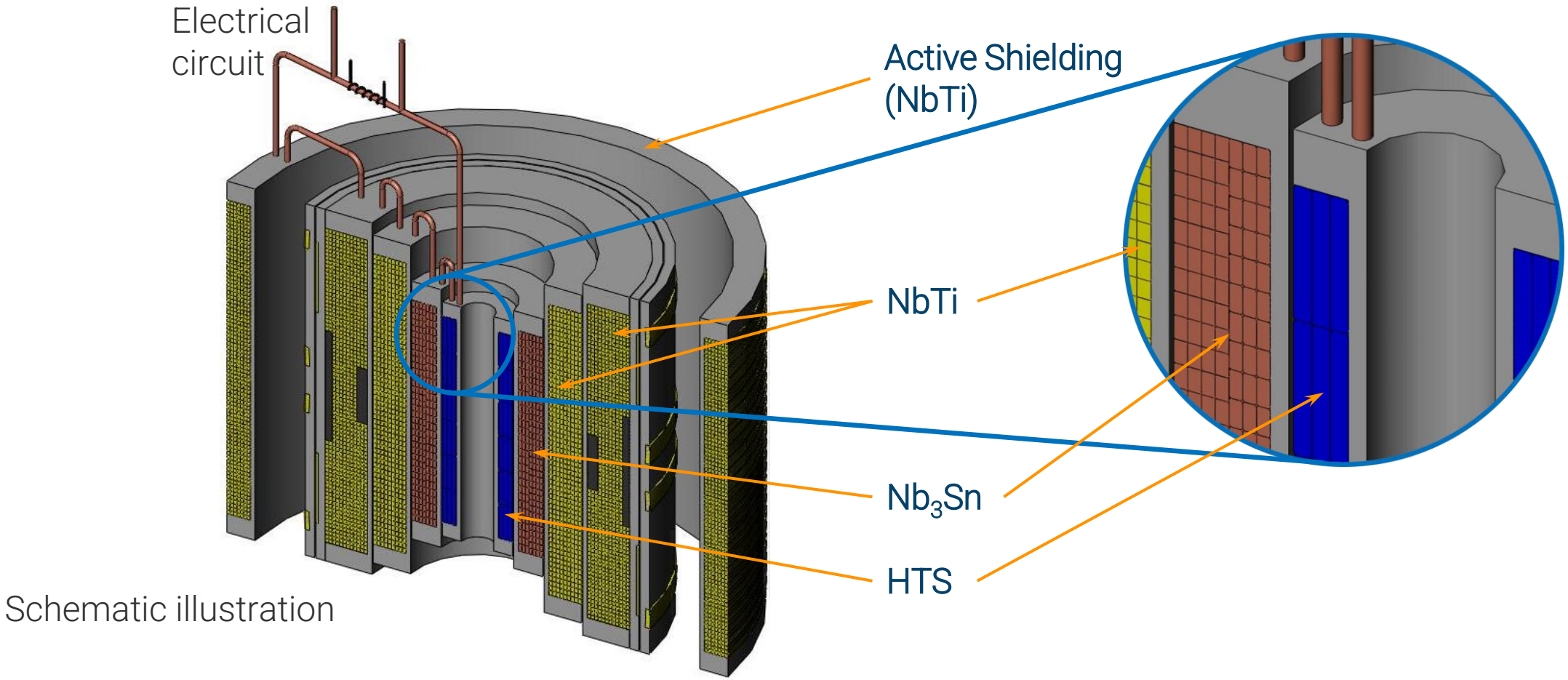
Sugar signals -> dispersion gain with increasing field strength



NMR systems at Bruker

> Overview NMR Portfolio & status UHF program

How it looks like: HTS-LTS hybrid magnet



Schematic illustration

- **Concentrical solenoids** connected in series
- Efficient **grading** of conductor performance and price

Bruker's HTS coils: insulated solenoidal winding of REBCO tapes

- REBCO tapes
  - Chosen more than15 years ago, ReBCO tapes showed great potential over other HTS conductors
  - main features, among others: mechanically self-supported tape
- Layer-wound HTS coils
  - minimum number of joints, because of their complexity
  - compact and homogeneous winding pack
  - Allows easier force management (hoop stresses)
- Insulated ReBCO coated conductors tapes
  - defined current path during energization and quenches
  - Faster to settle at final magnetic field

Layer-wound REBCO tapes

Bruker NMR magnet portfolio

Bruker BioSpin uses all the conventional superconductors in its magnets including NbTi, Nb_3Sn and HTS.

Bruker BioSpin has an active portfolio of NMR spectrometers with base frequency from **80 MHz** (1.88 T benchtop) up to **1.2 GHz** (28.2 T). The lower field magnets have also wide bore and a super-wide-bore versions. The total production capacity of a few hundreds of magnets per year.

Bruker Ultra-High-Field program: 2K 1.1 & 1.2 GHz (up to 28.2 Tesla)

HTS used to go beyond the limits of Nb3Sn

Within the Bruker UHF Program the successful implementation of REBCO conductors enabled the **highest field commercially installed** NMR spectrometer at the time:

1.1 GHz and 1.2 GHz Ascend spectrometers (2 K).

- 2019

Ascend 1.1 GHz:
HTS/LTS hybrid, 2 K (25.9 T)

- 2020

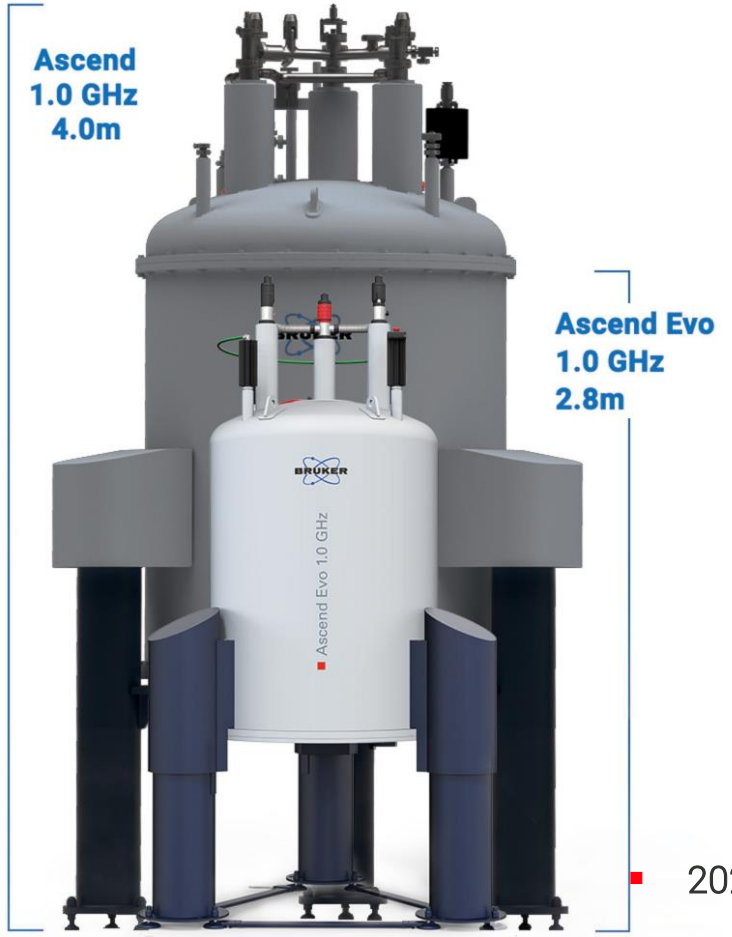
Ascend 1.2 GHz:
HTS/LTS hybrid, 2 K (28.2 T)

Bruker Ultra-High-Field program: 1.0 GHz (23.5 Tesla)

2009 2K -> 2016 2K shielded -> 2023 4K shielded

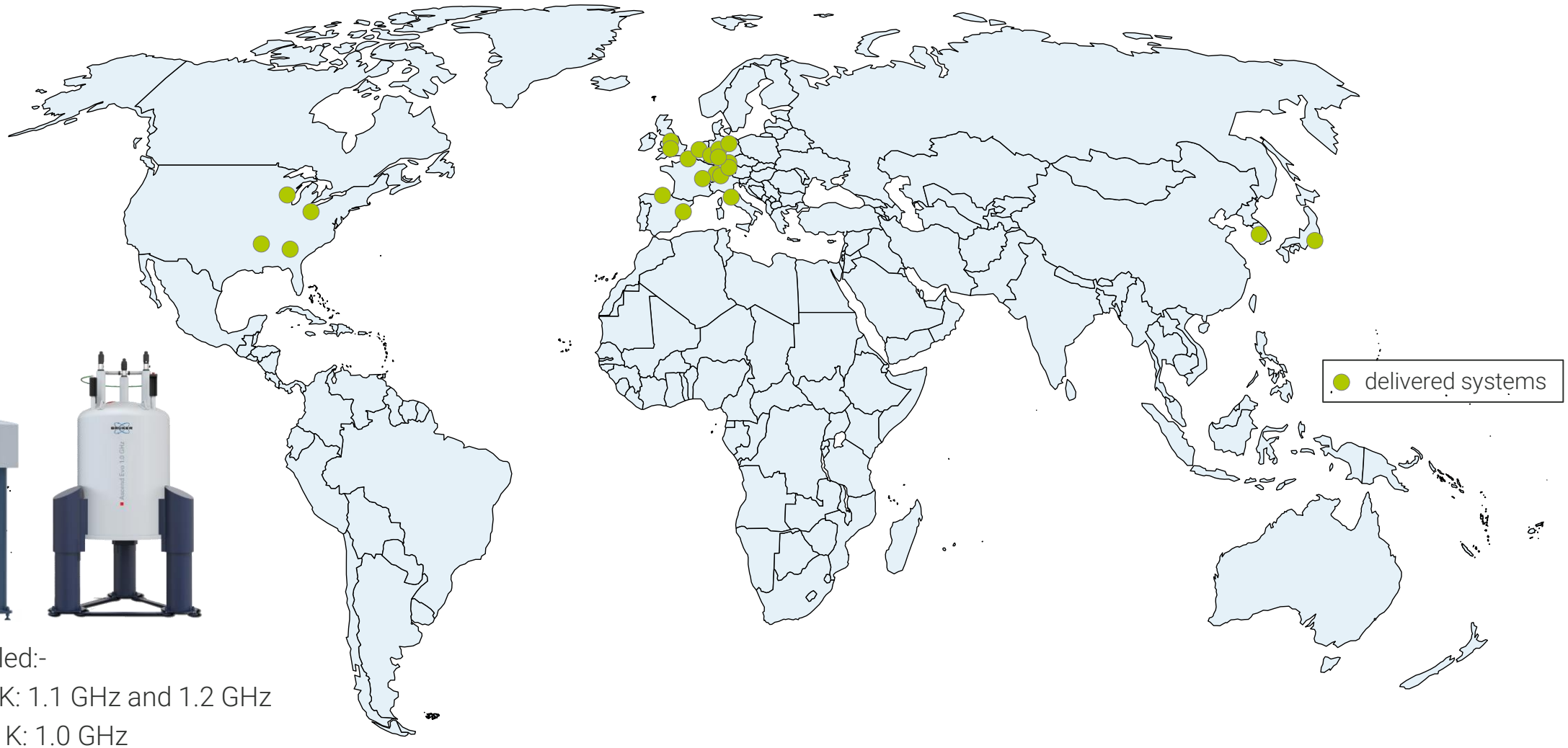
Another usage of HTS -> used to substitute Nb3Sn

- 2 K (sub cooled) → 4 K (standard liquid Helium)
- Two-stories → single-story standard laboratories
- Total weight reduced to < 1/3
- Helium boil-off reduced to < 1/3
- He hold time increased by 2 x
- Stray field 5 Gauss surface reduced to roughly 1/4



Size comparison of Ascend 1.0 GHz (LTS only, 2K) and Ascend Evo 1.0 GHz (HTS/LTS hybrid, 4.2 K)

1.1 GHz, 1.2 GHz and compact 1.0 GHz systems installed worldwide

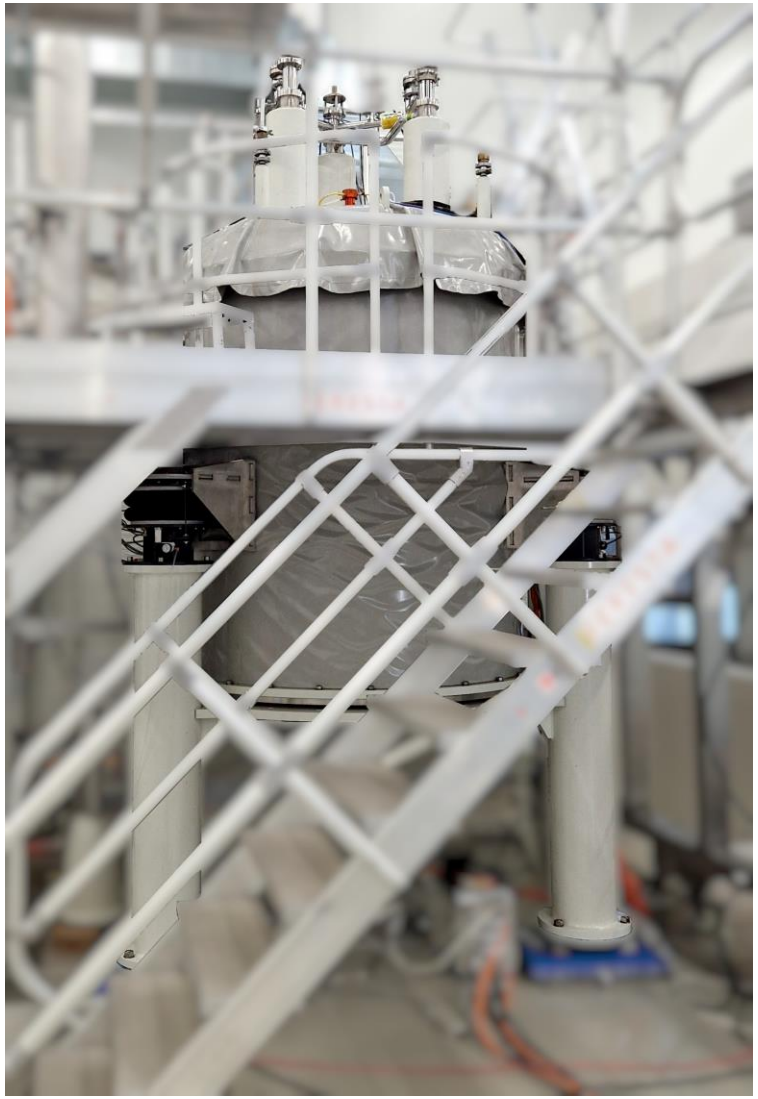


Bruker has installed:-

- 17 magnets - 2 K: 1.1 GHz and 1.2 GHz
- 3 compact - 4.2 K: 1.0 GHz

1.3 GHz Magnet (30.55 T)

- In 2024 Bruker has built and tested a prototype of a 1.3 GHz (30.55 T) spectrometer for high-resolution NMR.
- The 1.3 GHz HTS/LTS hybrid magnet has **entirely superconducting coils** and operates in **persistent mode**, with the **NMR-class** homogeneity marking a **new world-record.**
- The 1.3 GHz magnet follows the design solutions of the 1.2 GHz magnet, fits into the same cryostat and has the same helium/nitrogen consumption as a Bruker 1.2 GHz magnet, with only a slightly larger (+ 5%) stray field radius.

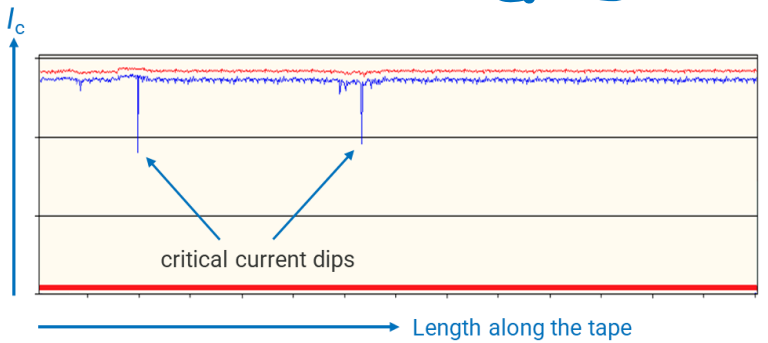


REBCO tapes

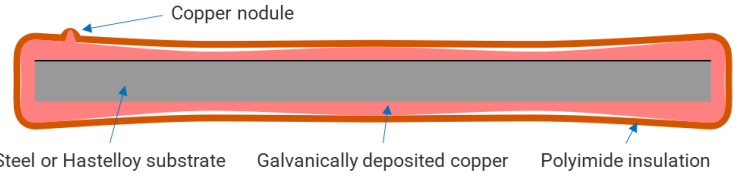
> Maturity and gaps, referred to NMR-grade conductors

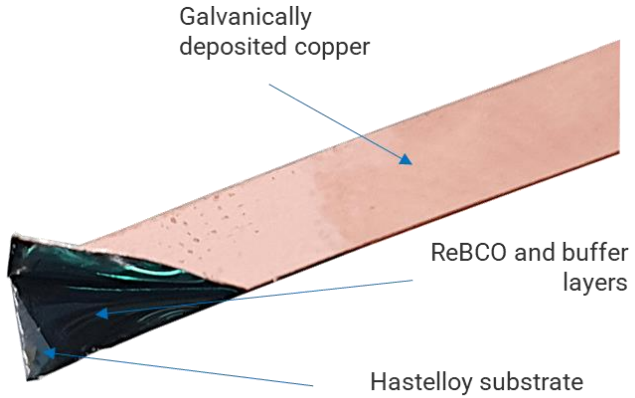
REBCO conductor: Today *vs* Beyond 30 tesla

Feature requiring attention	Today's requirements	Future (>30 T)
Piece length	300-900 m without Ic dropouts	Lengths ~ 1km in a steady supply
Cu homogeneity	Uniform thickness around the conductor (not always a standard for every supplier)	Uniform thickness around the conductor, avoid voids in the winding package
Electric insulation	Fully insulated	The thinner, the better, but still reliable
Critical current	10 T, 4.2 K perp. > 350 A	> 500 A
Mechanical Properties (substrate)	Hastelloy is the material of choice and standard reference of every supplier	Hastelloy
Uniformity along length & prod yield	No Ic drop-outs (single strand, no cables)	Higher yield of long high quality tapes (price reduction)



Tapestar™ measurement (symbolic data)

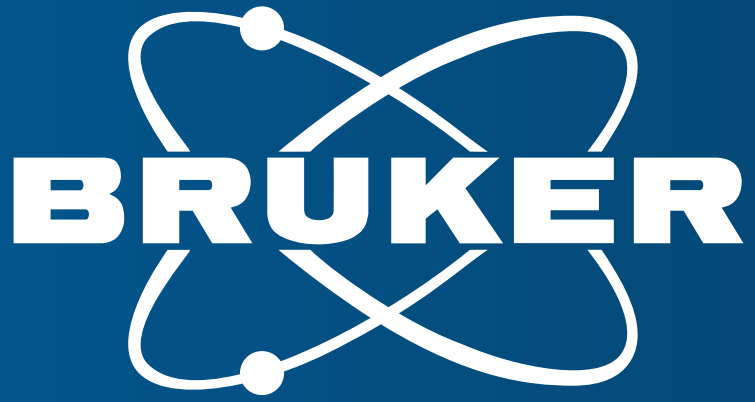




Magnet technology: Beyond 30 tesla

Feature	Future
Force management	Higher fields, bigger dimensions → how to deal with **stronger forces**
Quench management	Large quantity of REBCO → **quench protection** becomes more challenging
Conductor	**Tapes** → higher inductance, long manufacturing, availability **Cables** → current leads, availability, price
Temporal stability	Persistent *vs* Driven operating modes (NMR acceptance)
Spatial homogeneity	Bigger magnets → still possible to maintain required NMR homogeneity?
Magnet cost	Large HTS volume fraction → high system price → obstacle for commercial products

Thank you for your attention.



Innovation with Integrity