Ultra-High Field Magnets at Bruker

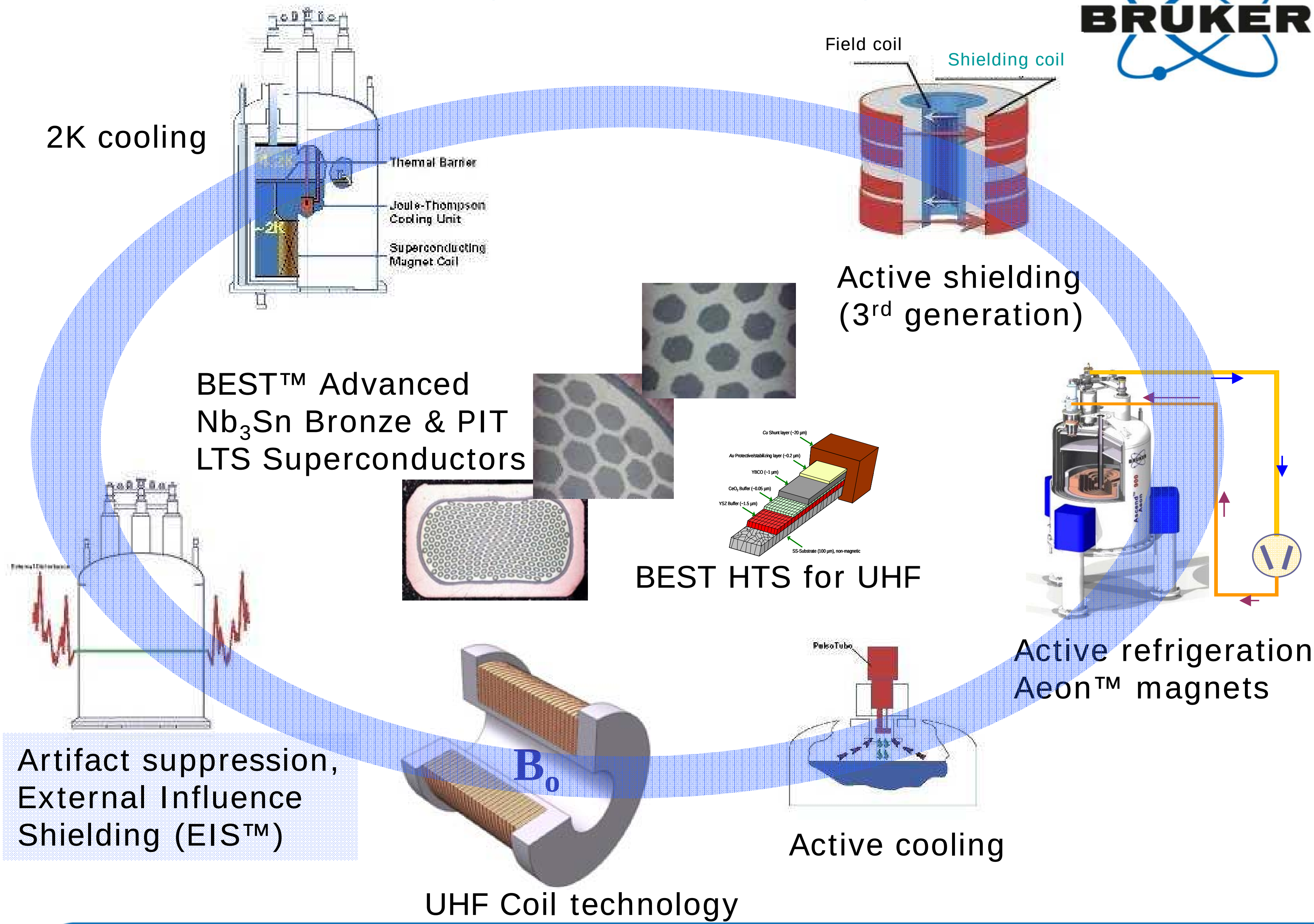
UHF Workshop at NIH, Nov. 12-13, 2015

Dr. Gerhard Roth
Bruker Superconducting Magnet CTO

Outline

- Bruker Magnet Technologies
- Highest field Bruker magnets today
  - Aeon 1 GHz 54mm NMR magnet (23.5 T)
  - 21T / 11cm FTMS and MRI magnet
- Towards 1.1 GHz 89mm and 1.2 GHz 54mm persistent, high-resolution NMR magnets

Key Bruker UHF Magnet Technologies



Bruker UHF Magnets Today- the state of the art:

- Actively shielded (3rd generation)
- Aeon closed loop cooling (LN2-free, no LHe boil-off)
- Persistent, homogeneous, ultra-stabilized

Aeon 900 54mm single-story NMR magnet

Aeon 21 T 11cm FTMS/MRI Magnet

Aeon 1 GHz 54mm NMR Magnet

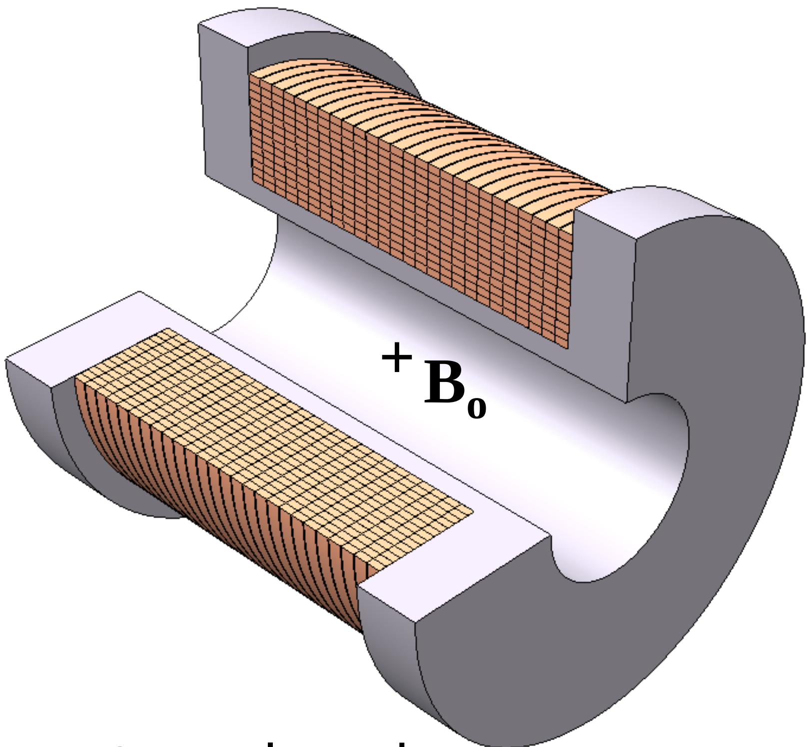
Bruker UHF Magnet Milestones

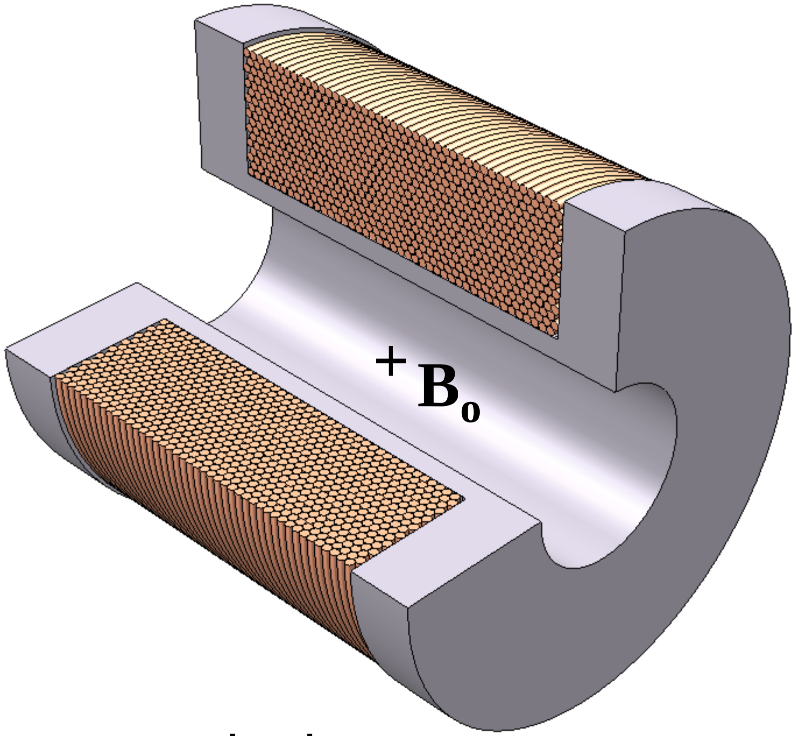
- 1992 First 750 MHz magnet
- 1995 First 800 MHz NMR magnet
- 1998 First 750 MHz wide bore magnet
- 2001 First 800 MHz actively shielded magnet
- 2004 First 850 MHz WB shielded magnet
- 2004 First 900 MHz shielded magnet
- 2006 First 800 MHz single-story shielded magnet
- 2006 First 950 MHz shielded magnet
- 2009 First 900 MHz WB shielded magnet
- 2009 First 850 MHz single-story shielded magnet
- 2009 First 1000 MHz magnet (unshielded)
- 2012 First Ascend Aeon 800 MHz WB magnet
- 2013 First Single-Story Aeon 900

Key UHF Technologies:

High current designs and rectangular NbTi, Nb_3Sn and PIT proprietary BEST™ superconductors

High current design	**Low current design**
$I_M = 2 \cdot I_o$	$I_M = I_o$



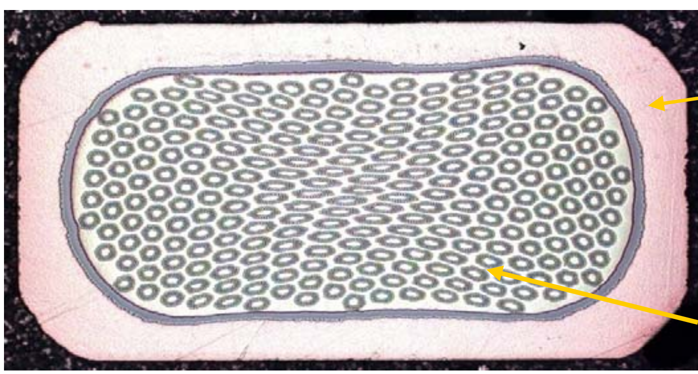


- rectangular wire
- conductor area = 4 mm²

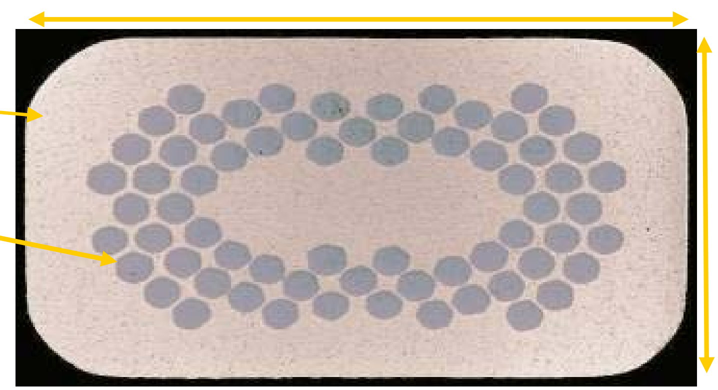
- round wire
- conductor area = 2 mm²

Advantages of Rectangular UHF LTS

- Higher current results in larger wire cross sections
- Better winding chamber filling factor
- Less insulation material in winding chamber
- Better control of forces
- Enables highest fields
- Enables smaller magnets & **smaller outserts for HTS magnets**



$(NbTaTi)_3Sn$-conductor

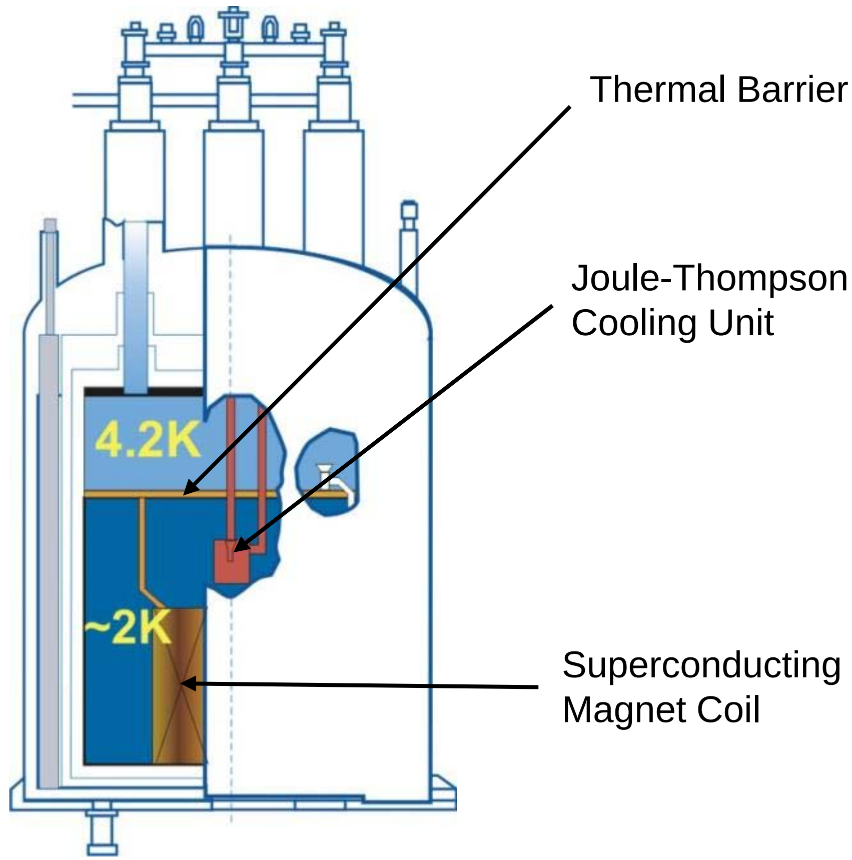


NbTi-conductor

UltraStabilized™ 2 Kelvin Sub-cooling:
used today for 850 MHz to 1.2 GHz

- Long term stable magnet
- Highest field strengths
- Increased magnet stability
- Higher safety margins
- Lowest drift rates
- Easy helium refills
- **Compatible with new Aeon™ & HTS technologies**

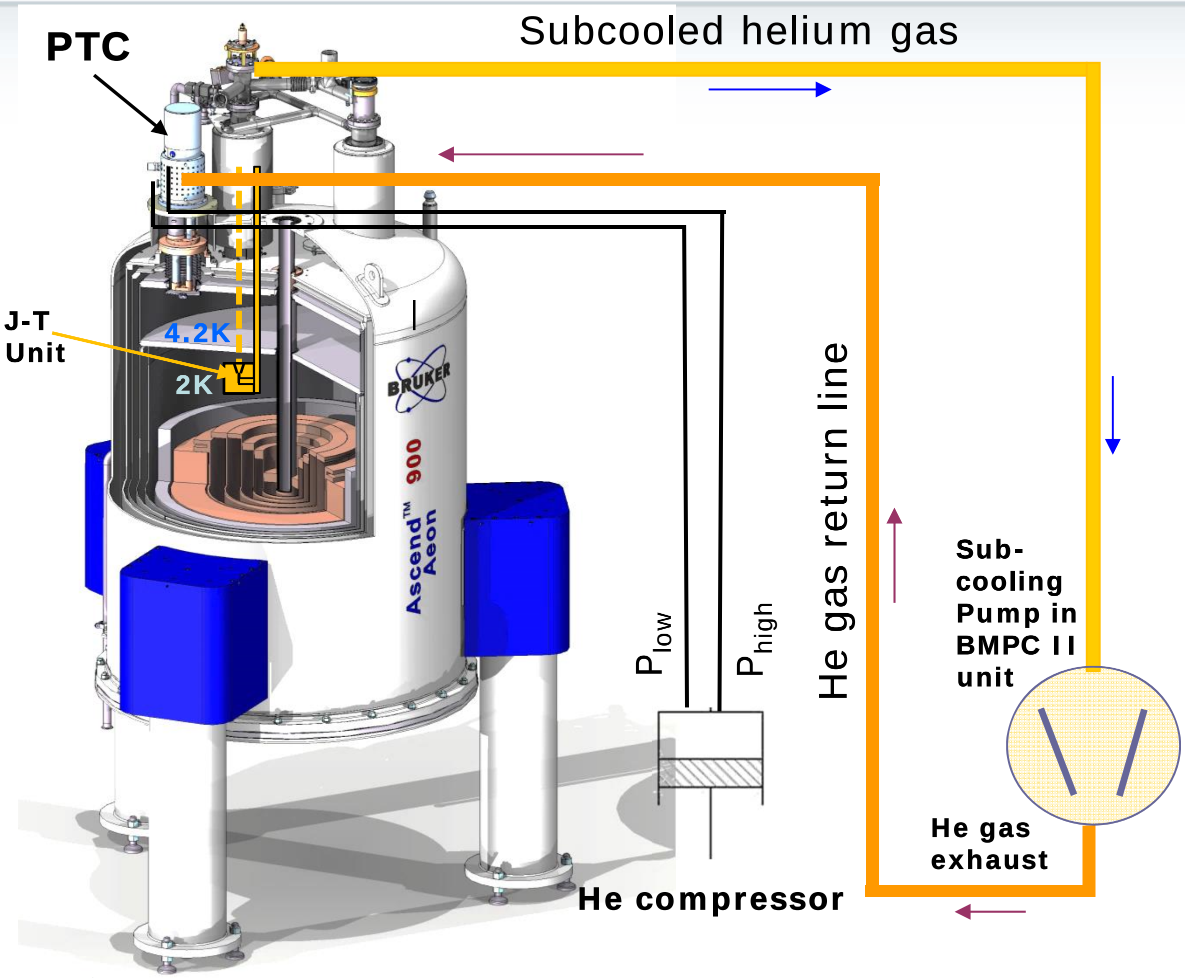
- Patented technology
- Pioneered by Bruker
- Proven track record
- Over 230 systems installed



UltraStabilized™ technology delivering unique performance, stability and safety

Aeon Active-Refrigeration: no compromise on High-Resolution NMR Performance

He-Re-Liquefaction for 2K sub-cooled magnets



- Sub-cooled LHe bath at same pressure of 1.05 bar as the 4.2K bath
- Low pressure (below 30 mbar) limited to the JT cooling unit maintained by pumping
- He gas exhausted from the pump at room temperature and fed back to the PTC
- Recovered He gas ***re-liquefied*** by the PTC
- Thermal shield cooled by the 1st stage of the PTC (N2 free, no nitrogen vessel)

Cryogen consumption during normal operation is eliminated

New: Actively-Shielded Aeon 1 GHz NMR Magnet

- **1.0 GHz 54mm** actively-shielded magnet
  - Greatly reduced stray field: 5G < 3.6 m radially, vs. < 12 m non-shielded
- **Aeon** active-refrigeration technology
  - LN_2 free – no liquid nitrogen refills
  - Zero He consumption under normal operation (He hold time >1 year)
  - Annual service
- **Upcoming Customer Installations:**
  - University of Bayreuth - **delivered**
  - University of Toronto, Canada: Q2-16
  - Future capacity: **6-8 systems per year**
- **Main Applications:**
  - **Intrinsically Disordered Proteins**
  - **Structural Biology**
  - **Membrane Proteins, Aggregates**

Sub-cooled UHF Horizontal Bore Magnets for MRI and FTMS

17.6T/25cm MRI magnet for Neurospin Saclay, France (2010)

New: 21 T/11cm FT-ICR magnet for NHMFL in Tallahassee, FL (2014)

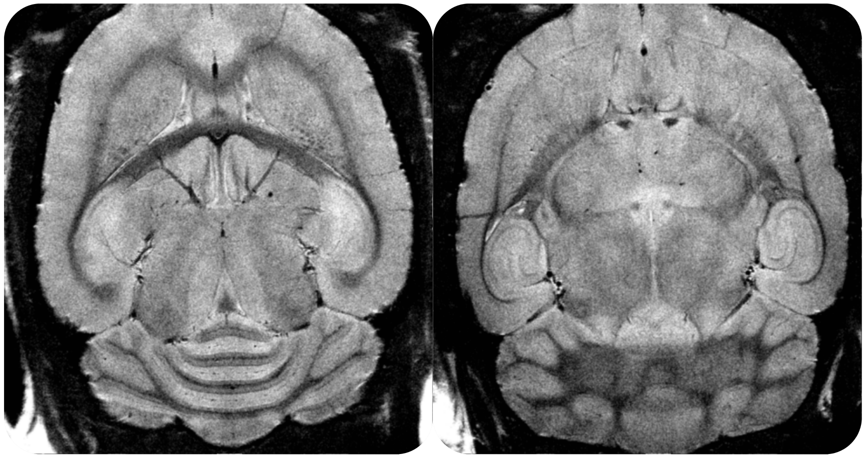
21T MRI *Mouse Brain Imaging*

BioSpec® 210/11 with MRI CryoProbe™ at 21 Tesla

21 T / 11 cm MRI Magnet

- 2 K operation with He re-liquefaction
- Liquid Nitrogen free
- No He consumption under normal operation
- 2 year service interval

- Ultra-high resolution mouse brain imaging *in vivo*
- T_2-weighted Turbo Spin Echo (RARE)
- High *in vivo* resolution (26 × 26 × 300) µm^3 acquired in 25 min



Acquisition details: RARE, 4 echoes, TR: 2000 ms, TE: 24 ms, FOV: (2.00 × 1.35) cm^2, resolution: (26 × 26) µm^2, slice thickness: 300 µm, scan time: 25:36 min

Towards a 1.2 GHz 54mm NMR Magnet

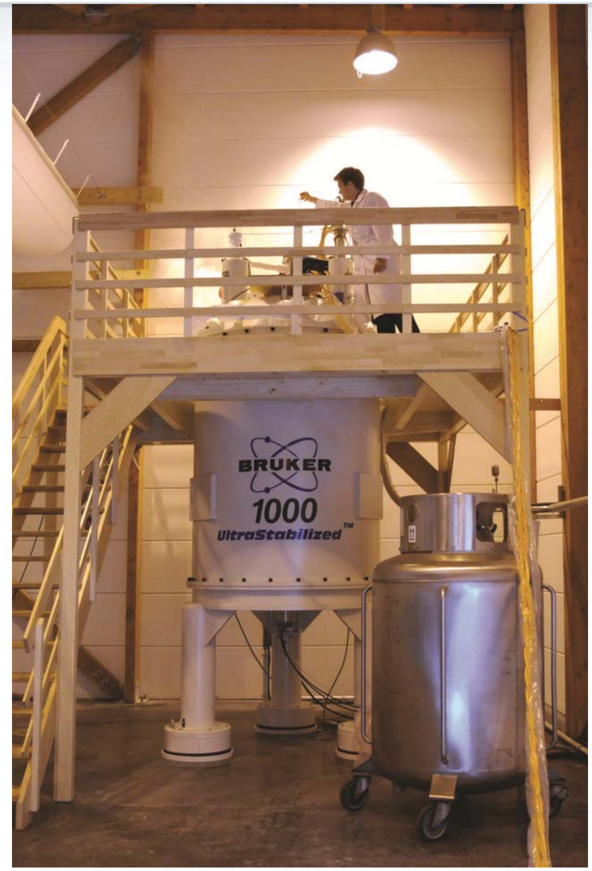
Goals: no compromise in NMR performance
persistent, homogeneous, zero LHe consumption

High-Temp Superconductor Challenges:

- Highest critical currents at B > 23 T
  High mechanical strength
- Reproducible, uniform properties along conductor length
- Stable properties over time at RT and 2 K
- **Long HTS lengths of many kilometers**

1.2 GHz (28.2 Tesla) Magnet Challenges:

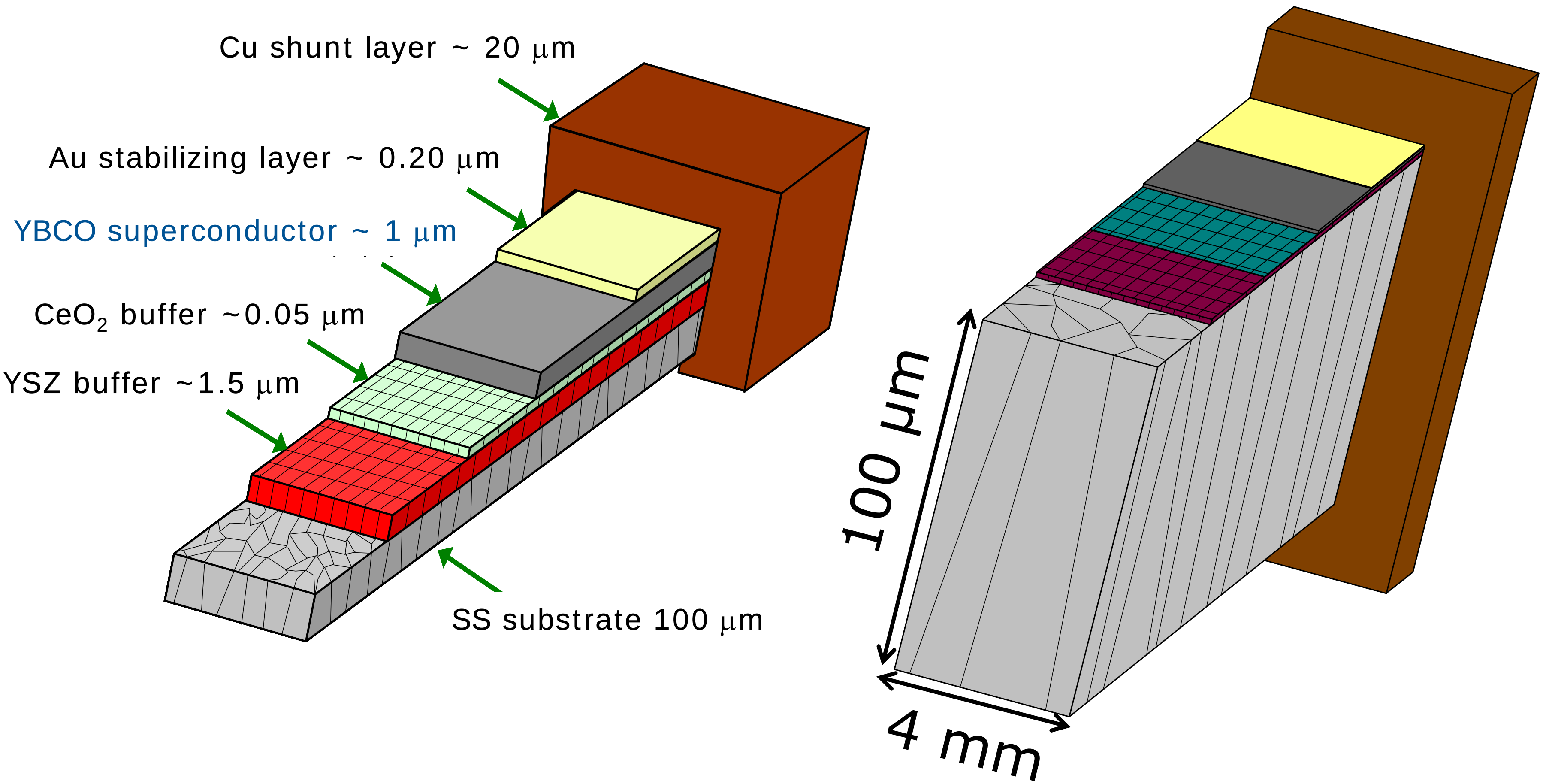
- Solenoid winding technology for tape conductors
- Shielding currents and influence on homogeneity
- Stable current distribution over time
- Stable properties under thermal cycling
- Quench protection
- Joint technology
- **Persistent Operation for low drift and to avoid enormous LHe consumption**
- **Small stray field, reasonable siting**



1 GHz (unshielded) Centre de RMN à Très Hauts Champs in Lyon, France

Yttrium Barium Copper Oxide (YBCO) HTS

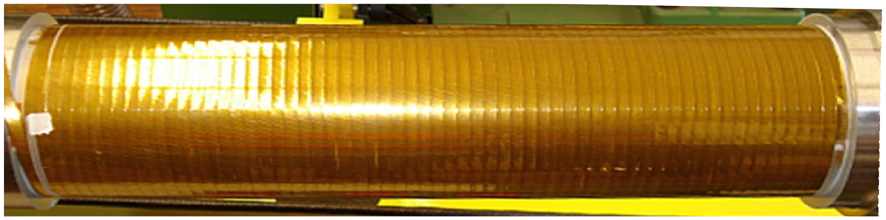
BEST (Bruker Energy & Supercon Technologies division, former ‚Vakuumschmelze')



Exploration of YBCO properties:

We have conducted numerous tests of tape properties and of solenoid windings in LTS high-field outsert magnets to clarify:

- Tape properties
- Winding stability
- Force resistance
- Jointing
- Influence on homogeneity
- Reproducibility
- Quenching and protection



YBCO Test coil solenoid (28 layers)

28 layers

12 layers

Results

- Proprietary YBCO tapes are suitable for >1 GHz UHF magnets
- Stable solenoid windings achieved as precondition for high-resolution NMR
- Shielding current issues can be addressed
- Quench concept allows safe quenching of HTS coils

→ Based on these results, final magnet design has been started

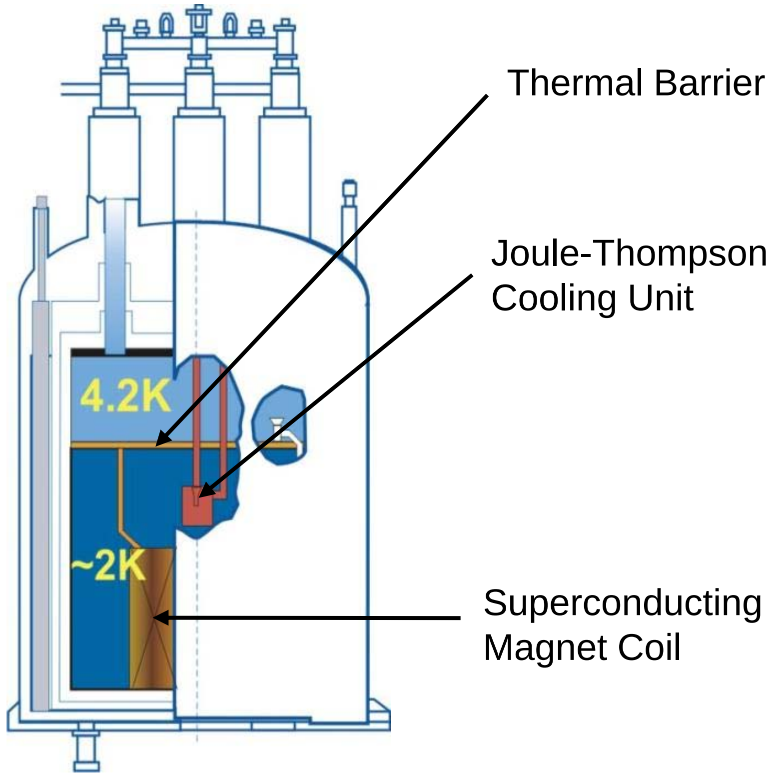
Bruker 1.2 GHz 54mm NMR Magnet

- Magnet will have implemented all key Bruker LTS technologies
  Proprietary YBCO High-Temperature Superconductors (HTS) beyond 1 GHz

➔ 1.2 GHz magnet design:

- **sub-cooled (2K)**
- **actively shielded**
- **actively cooled (Aeon)**
- **persistent**

- **First delivery expected in 2017**
- **Production rate of 4-6 magnets p.a. expected by 2018**



UltraStabilized™ technology delivering unique performance, stability and safety

➔ No compromise in high resolution NMR performance

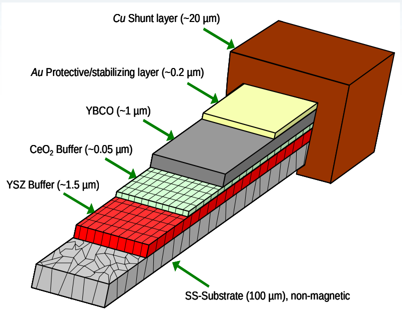
1.2 GHz Magnet Design
(current status)

- Magnet will be reasonably sized and will only be slightly larger than 1 GHz
- Magnet will be actively-shielded
- Stray field (5 G): < 4.3 m radial
- Minimum ceiling height: < 6.5 m
- Containing no liquid nitrogen
- Aeon technology for He re-liquefaction
- No liquid He-consumption during normal operation
- No special siting issues expected

1.1 GHz WB Magnet Design
(current status)

∅ < 1.8 m

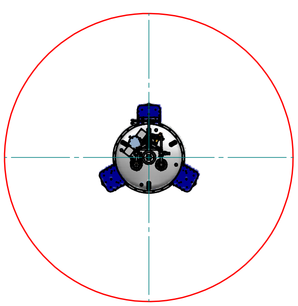
min. ceiling height < 6.5 m



- 89 mm RT bore
  Very similar to 1.2 GHz, except for inner sections
- Same size and stray field as 1.2 GHz
- Actively shielded and actively refrigerated
- Aeon technology with 1 year service interval

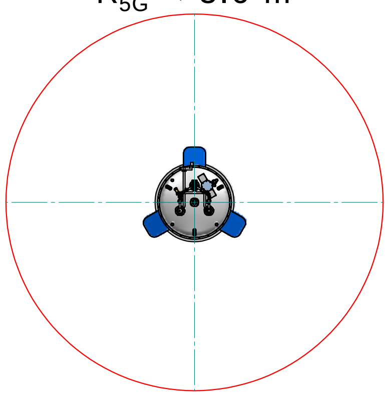
Aeon 1.2 GHz Stray Field: *5 Gauss line*
➔ *active shielding for reasonable siting*

R_{5G} < 2.8 m



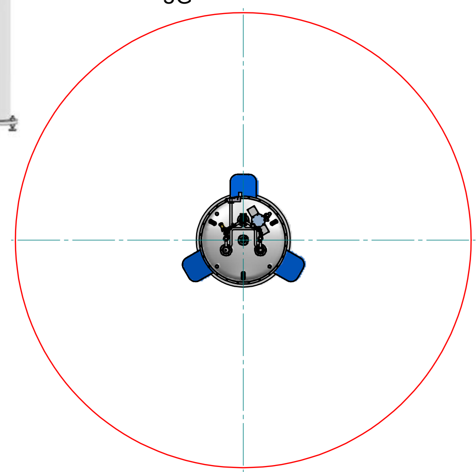
Ascend Aeon 900

R_{5G} < 3.6 m



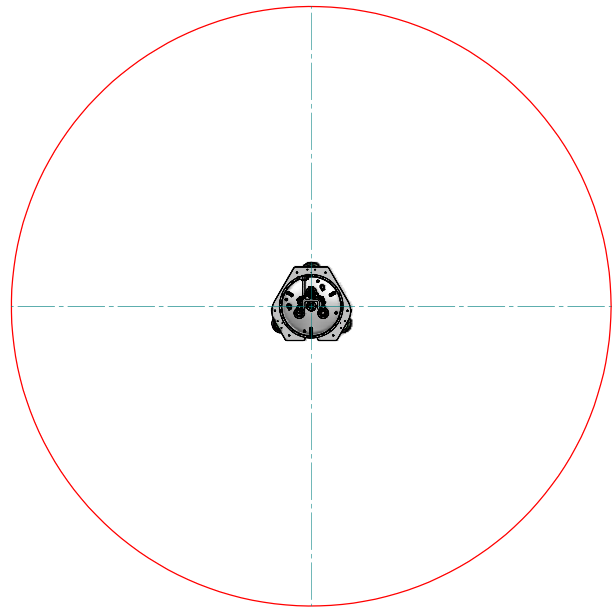
Aeon 1000

R_{5G} < 4.3 m



Aeon 1200

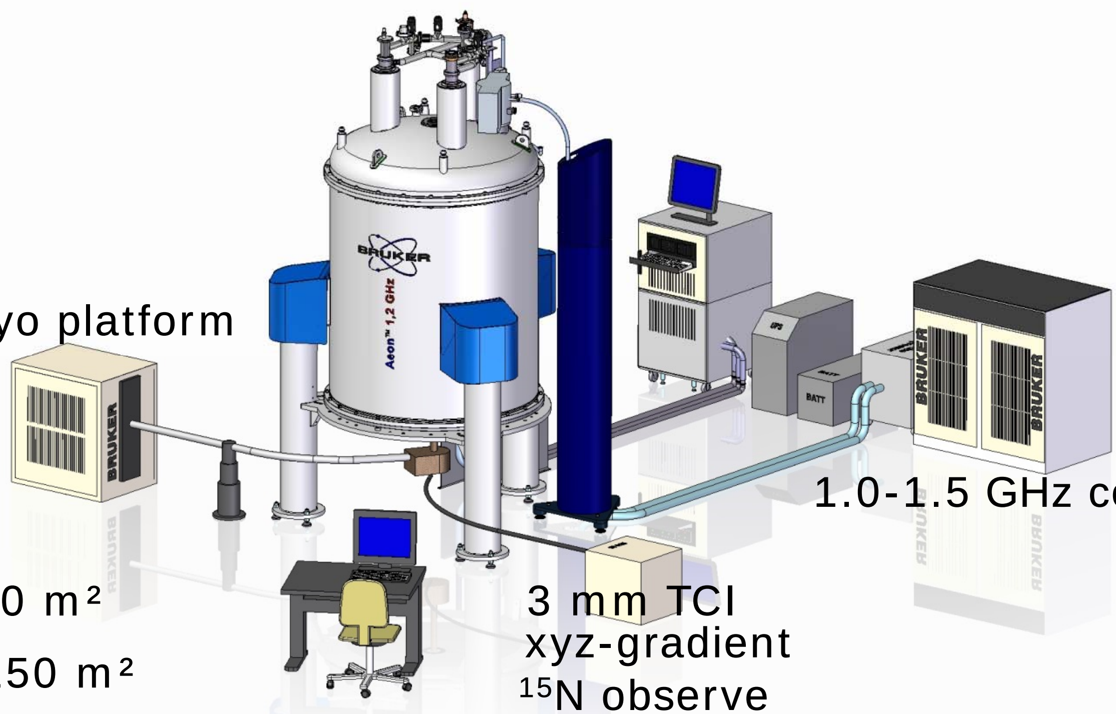
R_{5G} < 6.1 m



800 Unshielded
(1995-2002)

Aeon 1.2 GHz with Cryoprobe (or 111 kHz MAS probe): *siting example*

Space requirement: < 70 m^2



Comparison:

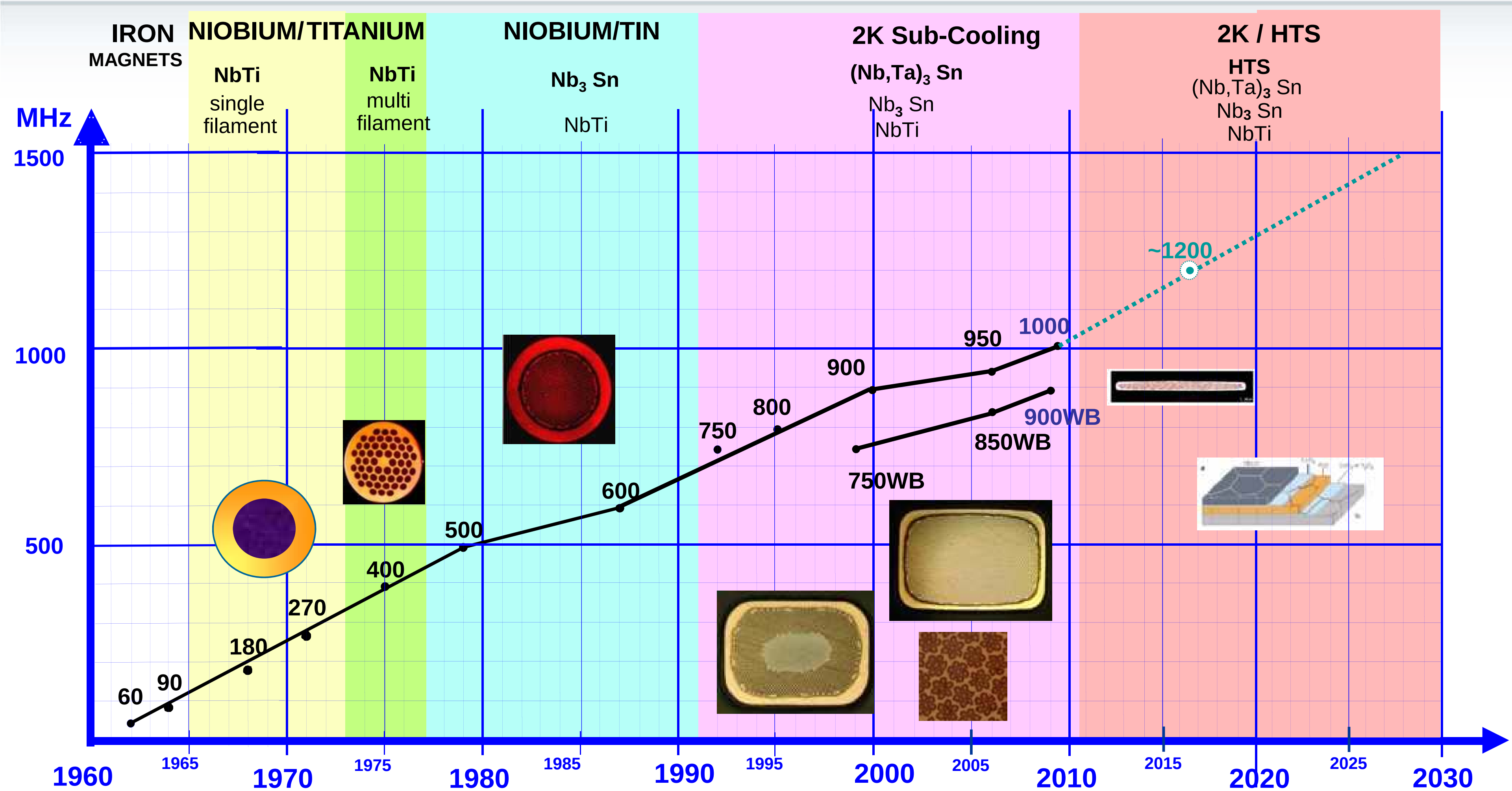
Compact AA 900 < 30 m^2

800 US < 150 m^2

No special siting issues expected for Aeon 1.2 GHz HR NMR!

High Field NMR Milestones

Empirical Law: *5 years per 100 MHz step*



Magnets having full NMR specifications in persistent mode

Innovation with Integrity