Superconducting Materials

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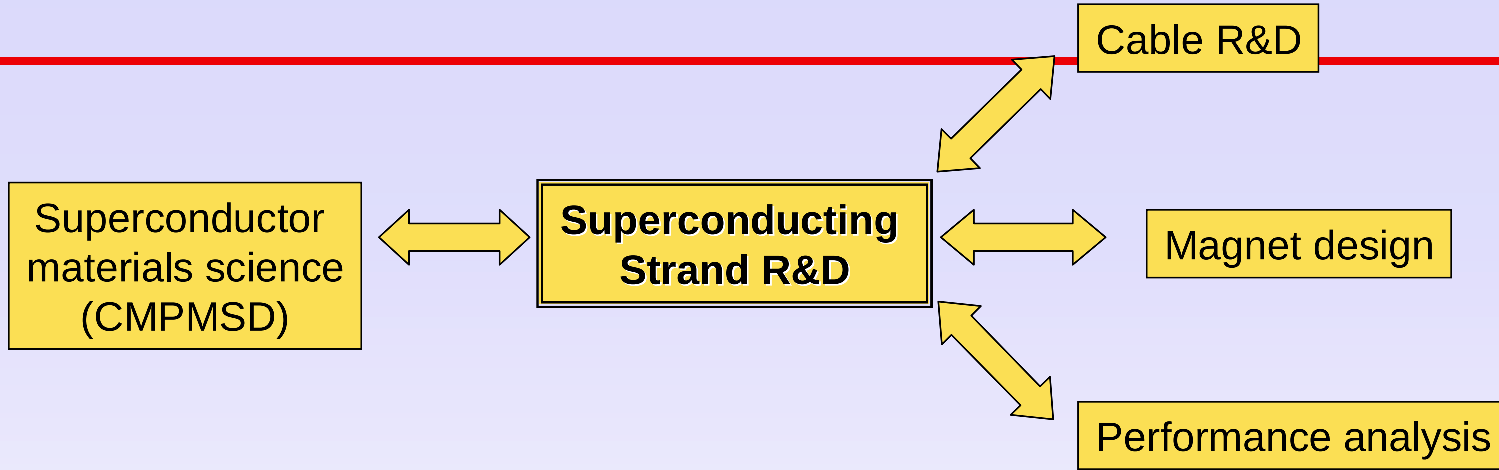
Main Goals

Superconducting Materials Development in the Magnet Division (SMD) has always focused on magnets for particle accelerators and experimental facilities

- Understand conductor requirements of magnets being developed
  - Study properties of superconducting wires and tapes made in industry
  - Address conductor-related issues that impact magnet performance
  - Provide data for use by magnet builders
- Provide superconductor support for programs at BNL/SMD
- Advance "the state" of conductor art
  - Collaborate and provide input to conductor manufacturers
  - Play leading role within US-HEP community
  - Collaborate with institutions worldwide to develop superconducting technologies

This program has unique aspects



- Synergistic interactions between CMPMSD and SMD fertilize discussion and promote scientific innovation
- Vertical nature of coordinated effort (from basic mechanisms to cables and magnets) provides understanding within a complete context
- Direct, synergistic relationships with US industry facilitates scientific exchange, faster improvement of properties, better responsiveness to program needs, and better reliability of strand supply
  - Chiefly Oxford Instruments – Superconducting Technology
  - Other smaller companies like Supercon, Superconducting Systems, Supergenics, HyperTech

Recent Advances We Have Pioneered

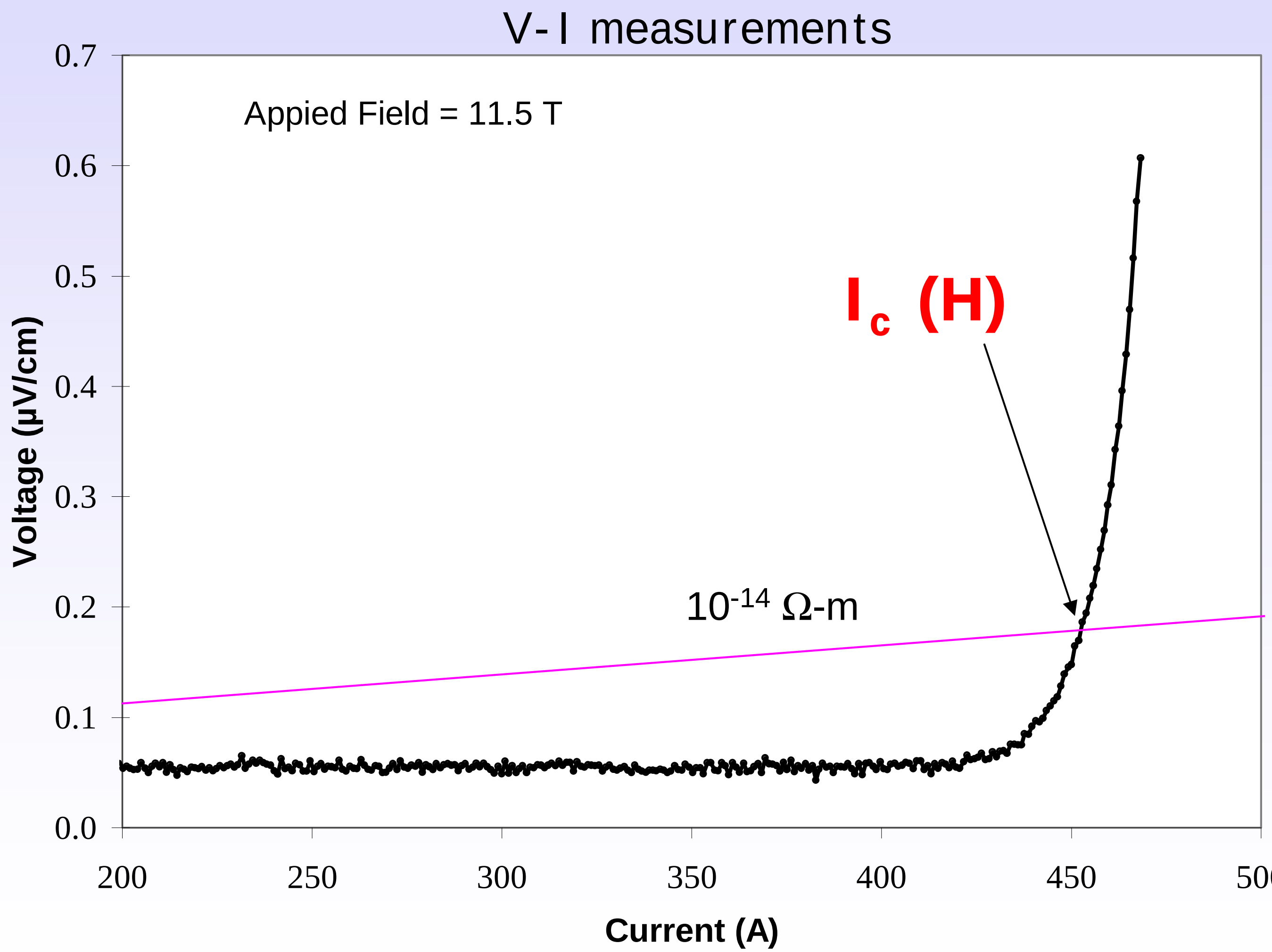
- High current cable testing
  - Supporting projects like CBA, DESY, SSC, RHIC, LHC
- Integrated reaction and test fixtures for high-Jc (critical current density) Nb3Sn strands
- Development of “react-and-wind” Nb3Sn technology
- Use of voltage-field (V-H) measurements to determine stability threshold of strands, in particular Nb3Sn
- Understanding of the vital balance between stability and performance for modern Nb_3Sn
  - This provided a workaround to make magnets successful (LARP)
- Understanding of superconductor cost
- HTS magnets

Present Activities

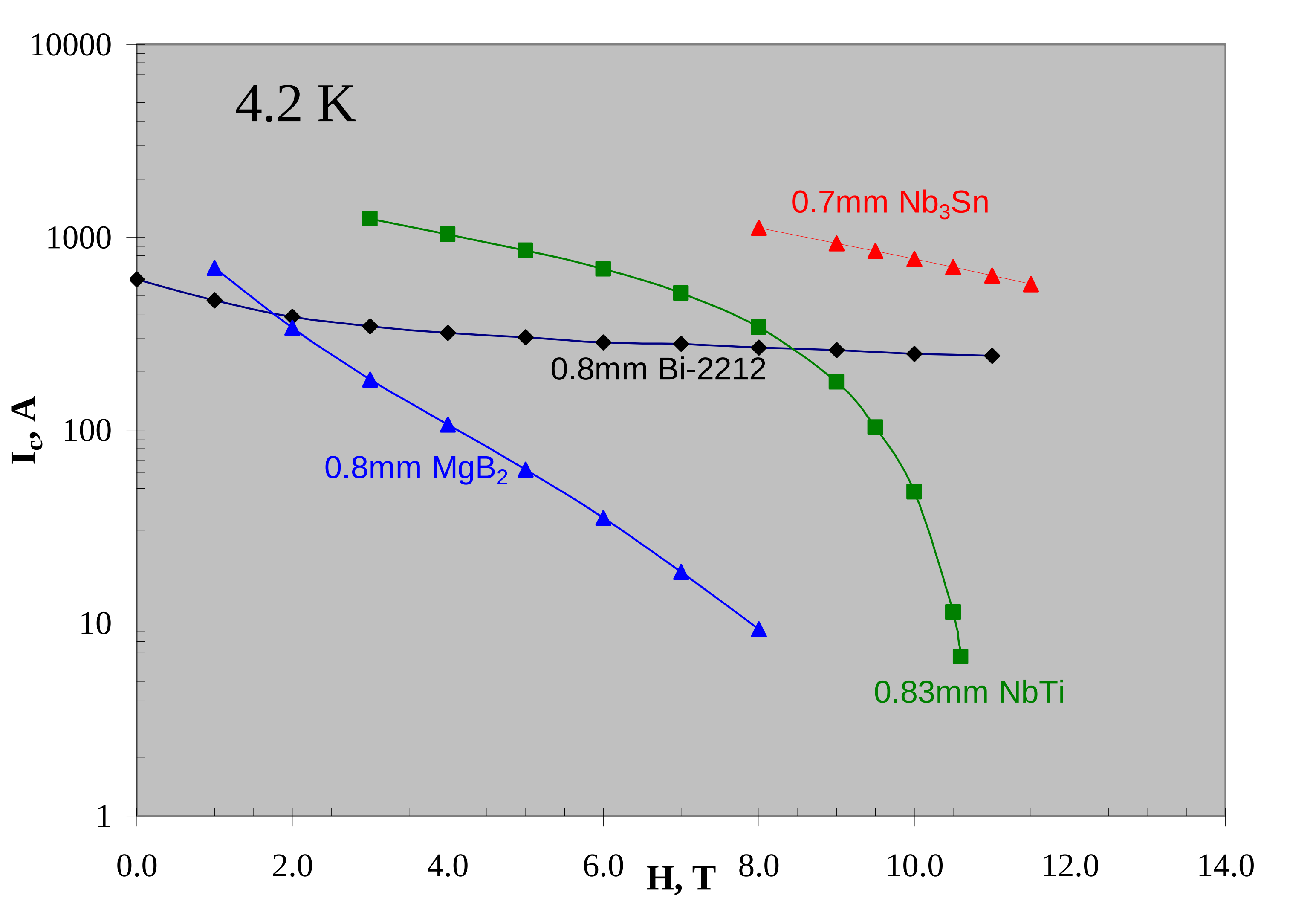
- Low Temperature Superconductor (LTS) Development/Testing
  - NbTi
    - Strand Testing
  - High-Jc Nb3Sn Conductor development
    - Strand Testing ⇨Critical current (Ic), Critical Current density ($Jc = Ic/A_{SC}$)
    - Heat treatment optimization
    - Stability Studies
    - Reducing effective filament size
    - Rutherford Cable testing
  - MgB_2 wire development (collaborate with Ohio State and industry)
  - LHC Accelerator Research Program(LARP) R&D
    - High-Jc Nb3Sn strand and cable
- High Temperature Superconductor (HTS)
  - Bi-2223 tape and 2nd –generation YBCO tapes (collaboration with American Superconductors)
  - Bi-2212 wire and cable (collaboration with Oxford Superconducting Technology and Showa, Japan)

Critical Current Ic
“Current-carrying capacity of wire”

First apply transverse field and then ramp up current till voltage is observed

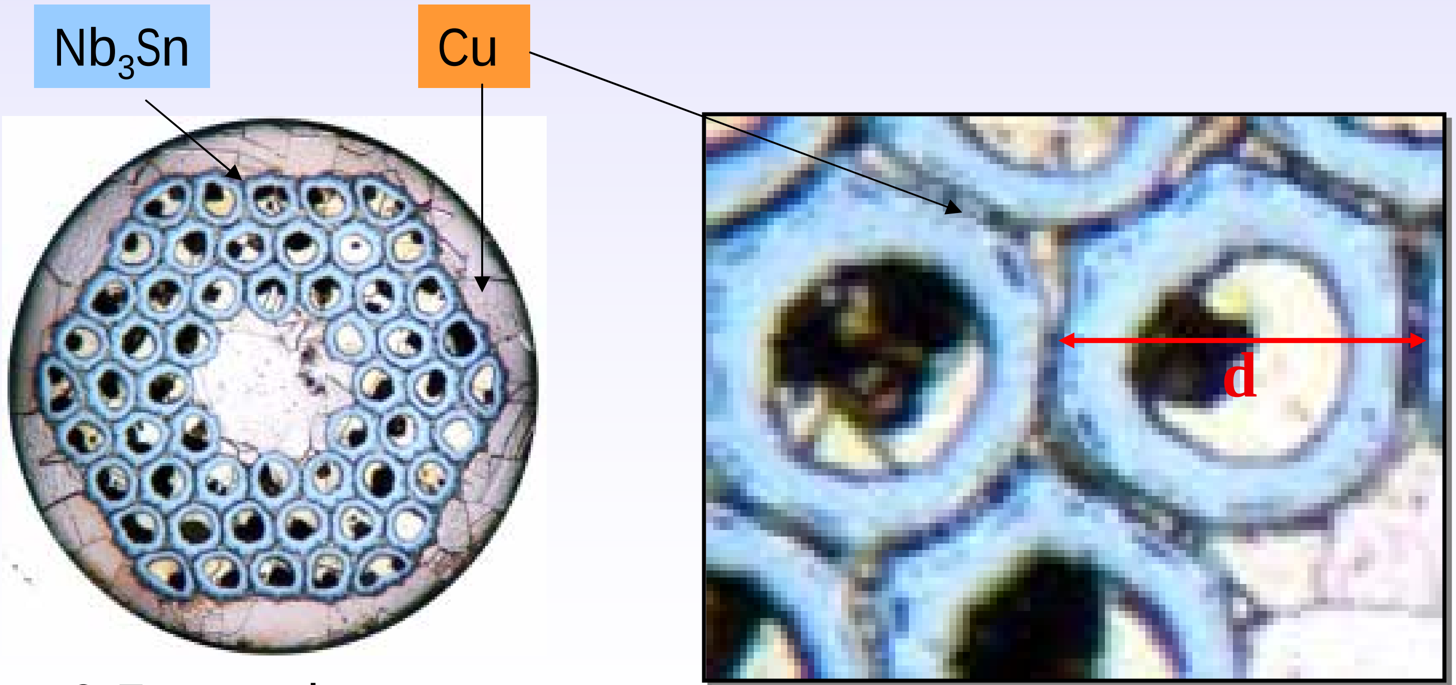


Strand Testing at BNL
Critical currents of superconducting wires- A comparison



Stability Studies - Key issue for high Jc-Nb_3Sn Strand

- High Jc Nb_3Sn multi-filamentary strands behave as a solid tube of superconductor of large diameter **d~ 60-100 μm** . (Typical NbTi filament diameter ~ 6-10 μm.) This leads to magnetic instability at low fields which is readily seen in magnetization measurements.



0.7 mm wire

Magnetization – Flux-Jump Instability

Magnetic moment of a wire in transverse changing magnetic field

$$\boldsymbol{M \sim J_c\, d}$$

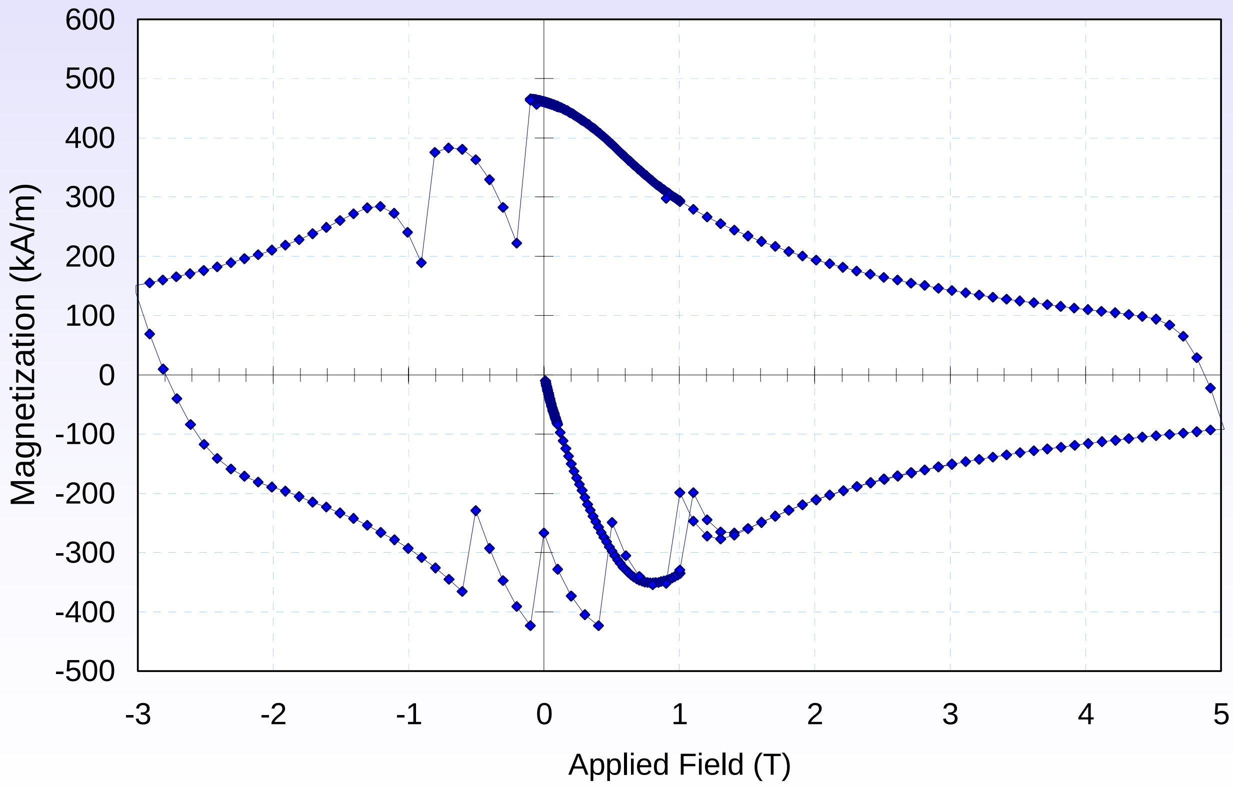
$$\beta = \frac{\mu_0 J_c^{\,2} d^2}{4C(T_c - T_{bath})} < 3$$

β=Adiabatic Stability

C=Heat Capacity, T_c=Critical Temperature T_{bath} =Bath temperature

The combination of high Jc and large d results in the loss of “adiabatic” stability at low fields

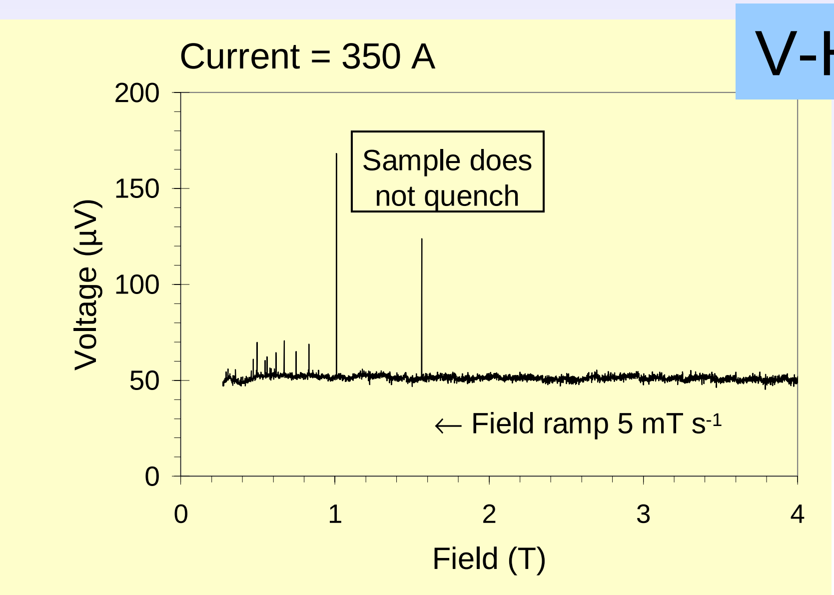
⇨ Flux-jumps

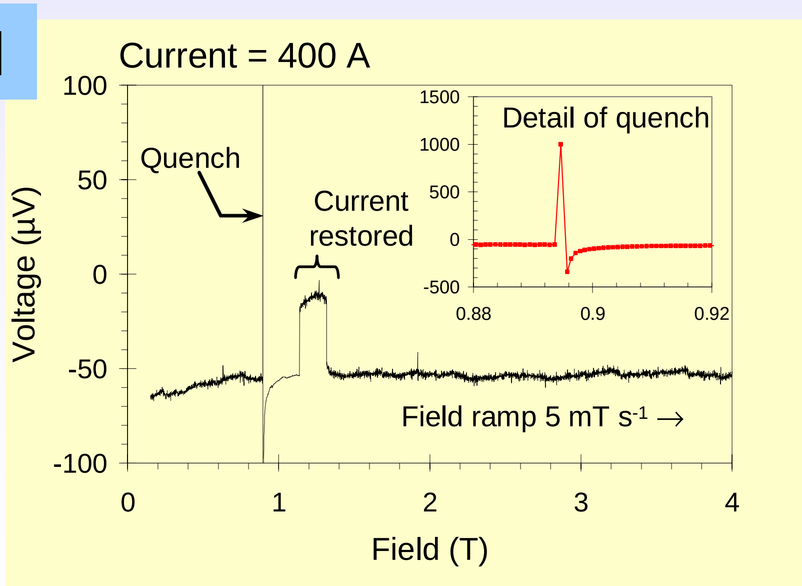


What if we take a wire carrying current and change the magnetic field and monitor the voltage across the wire, flux-jumps are observed as voltage spikes.

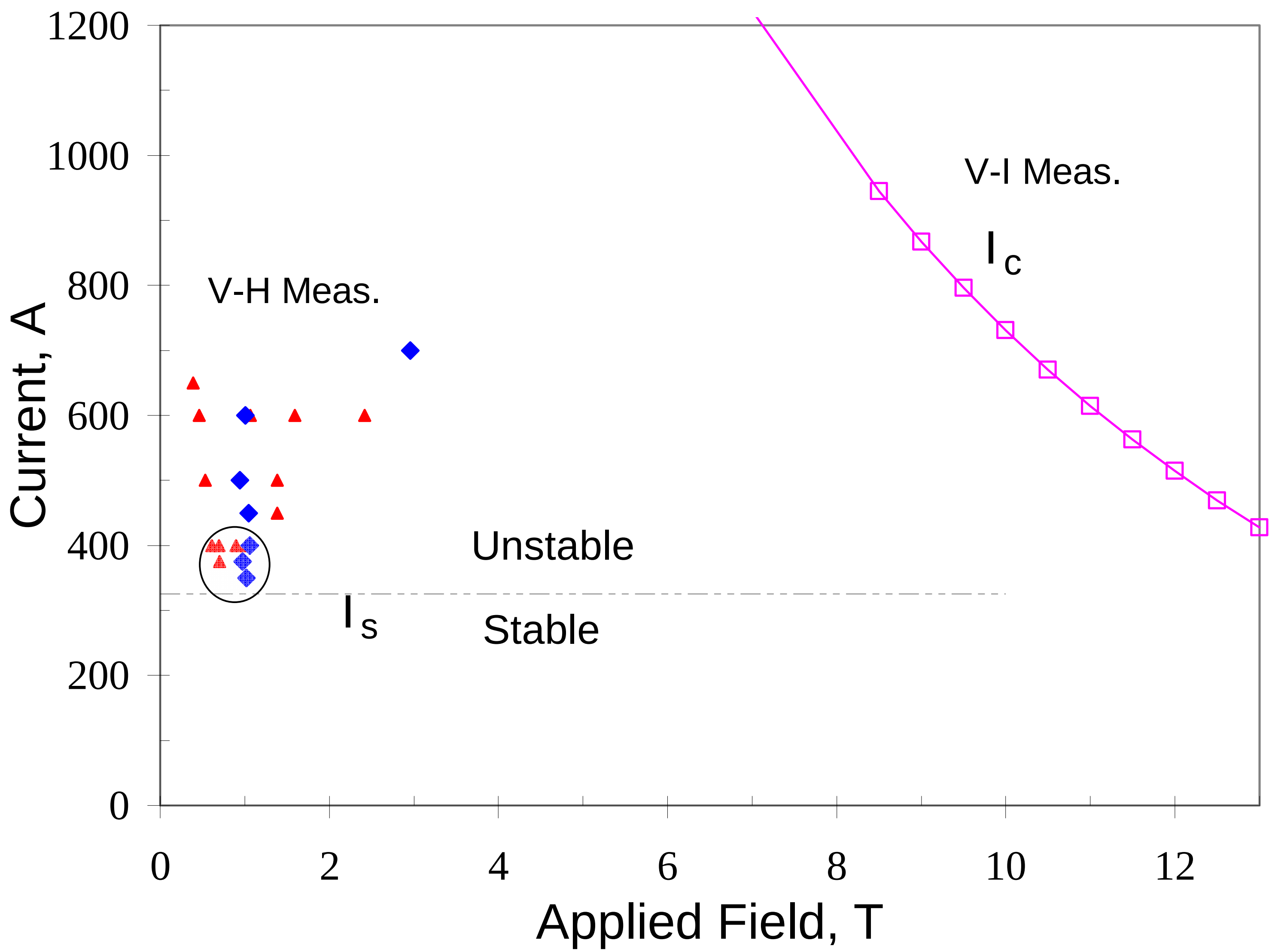
Above a “threshold” current **Is, the** wire will spontaneously “quench”

V-H

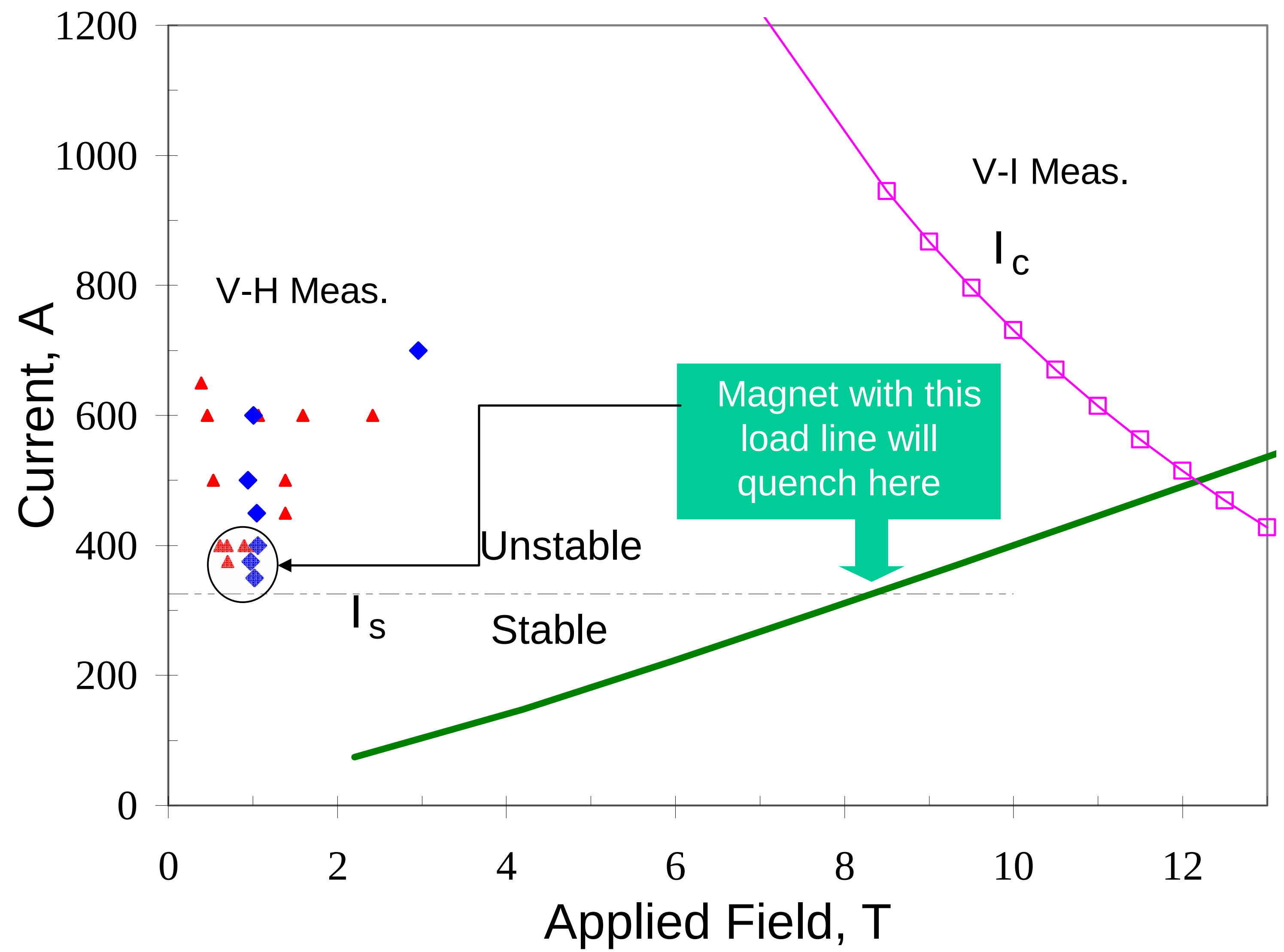




Will “flux jumps” initiate a quench in a magnet ?

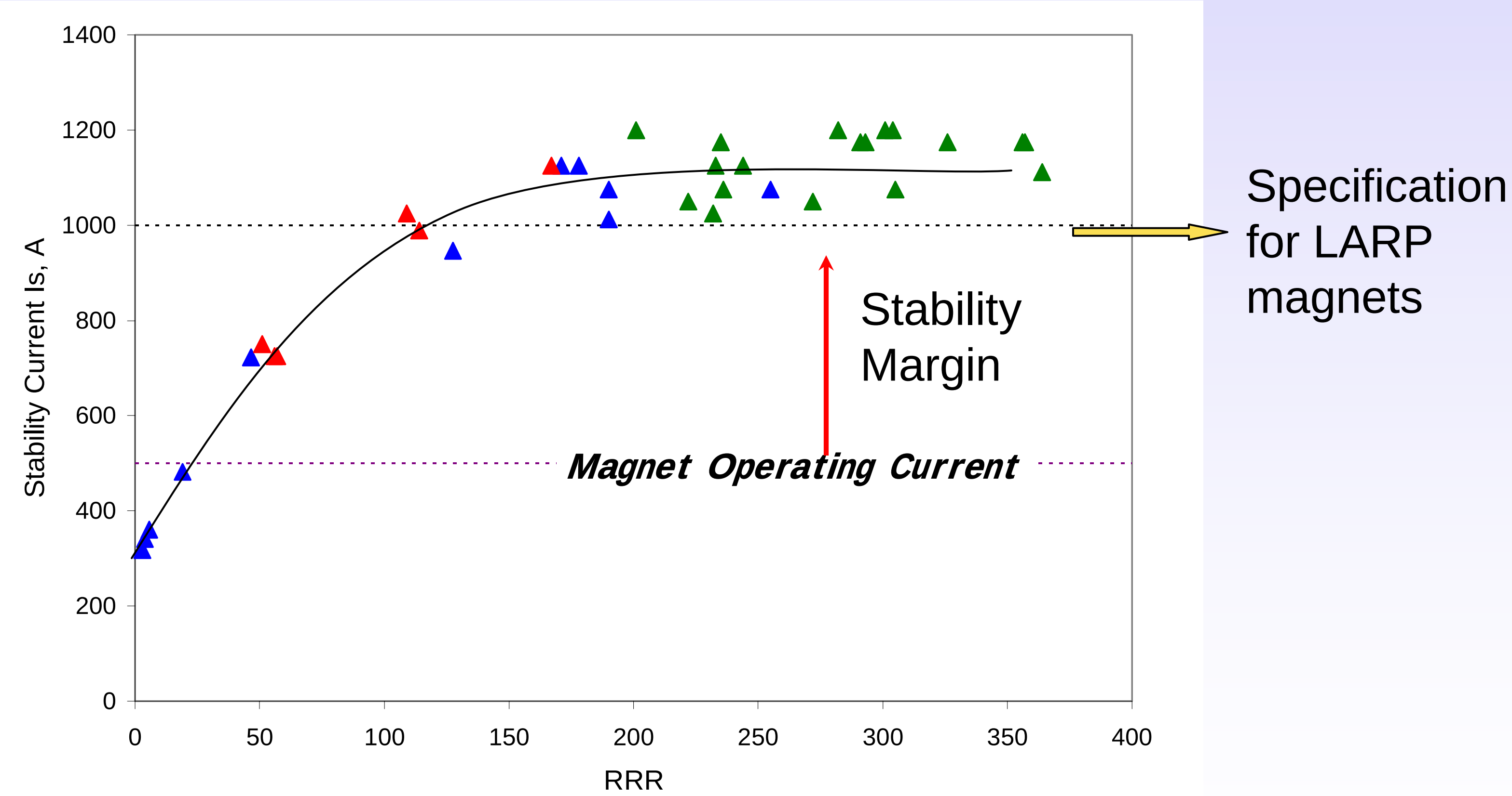


Impact of Stability Current on Magnet Performance



Can Magnets with unstable strands operate safely ?

Yes: if the resistivity ρ of the copper matrix surrounding the filaments is low or conversely if RRR is high (RRR ~ 1/ρ).



Stability margin achieved with only 10% reduction in Jc

LARP Program – Materials R&D

- Collaboration of BNL, FNAL and LBNL
- Development of stable high Jc Nb_3Sn wire and cable for high gradient quadrupole magnets G > 200-300 T/m (peak field at conductor ~ 12T-15T)
  - As shown BNL contributed significantly to this R&D
- SMD has a lead role in conductor R&D
  - Management of strand and cable R&D
  - Management of strand procurement from Oxford Superconducting Technology (OST)

Conductor Testing Resources

- Strand Testing
  - 8T/10T (4.2/1.9K) 60 mm bore solenoid
  - 12T 50 mm bore solenoid
  - New testing barrel design for Nb3Sn strands
  - Test current 1500 A
  - Strand diameters 0.3 mm to 1.0 mm
    - Wish list: 16 T, 2000 A
- SEM, Optical Microscope, at CMPMSD
- Magnetometer for magnetization tests to 5T
- Heat treatment facility for Nb3Sn strand and cable
  - Tube furnaces at CMPMSD
  - Large furnace at SMD
- Cable Testing
  - 7.5T, 75mm bore dipole magnet
  - Test current 25 kA

Summary

- Superconductor R&D at the Magnet Division provides an important resource in the development of magnets
- This program is at the forefront of superconductor technology for magnets
- Conductor testing and evaluation is an integral part of the R&D effort
- Resources are adequate for most superconducting materials except high field testing > 12T for strands and > 7.0T for high current composites like Nb3Sn cables