Damage of superconducting strands due to beam impact

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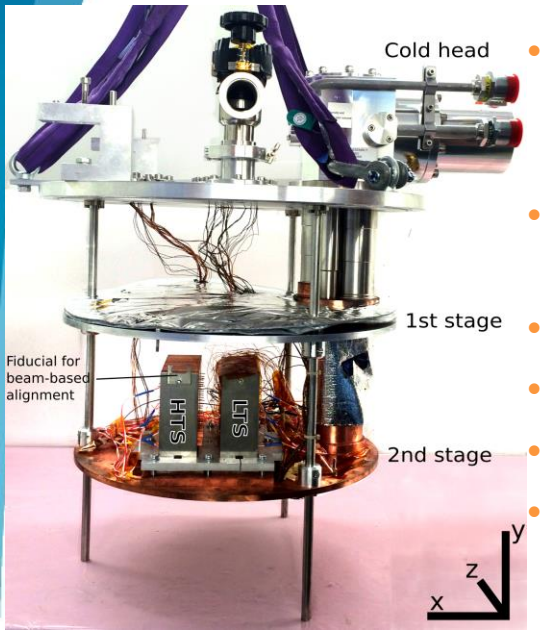
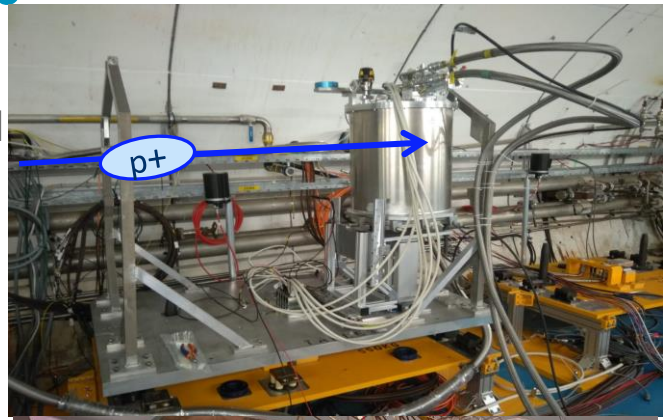
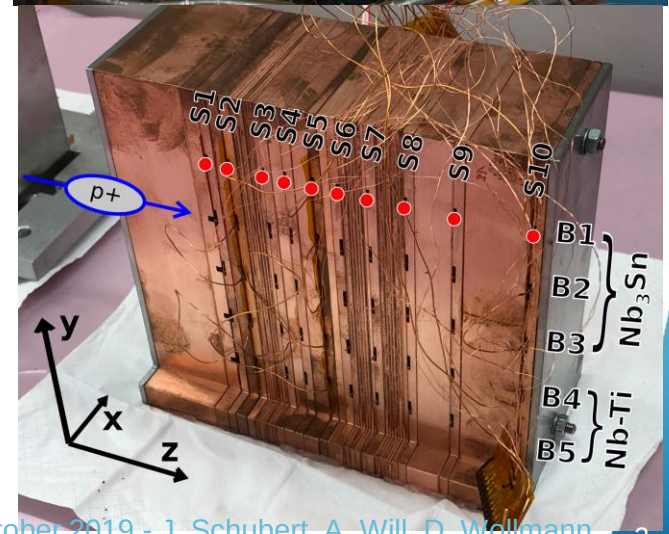
HiLumi HL-LHC PROJECT

Experimental set-up



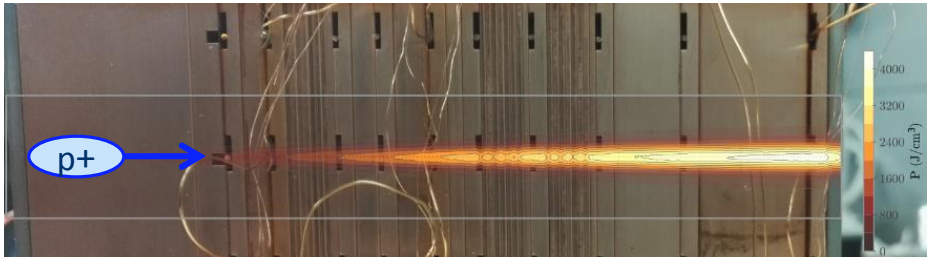
- Cryocooler based cryostat to cool samples to ~4K installed in CERN's HiRadMat facility
- Sc. strands placed within stacked copper holders
- 2 x 10 samples Nb-Ti
- 3 x 10 samples Nb3Sn
- 5 x 10YBCO tapes
- 10 shots of 3e12 p @ 440 GeV

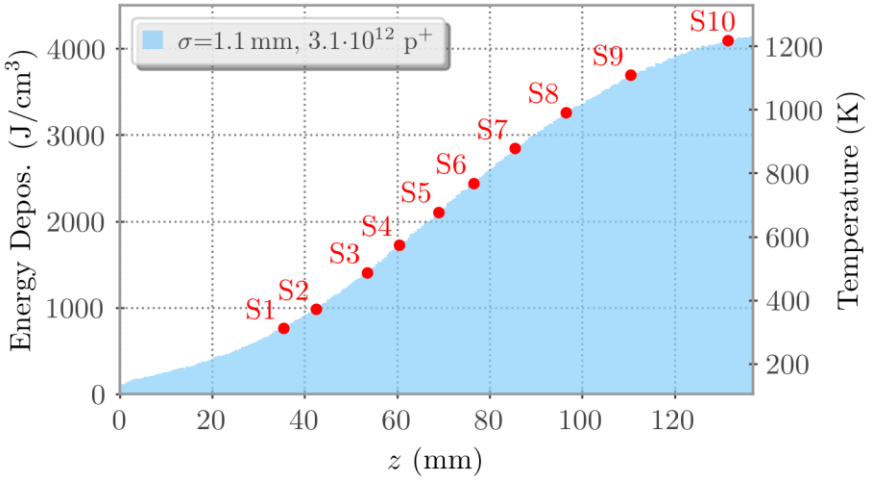




Energy deposition by 440 GeV proton beam

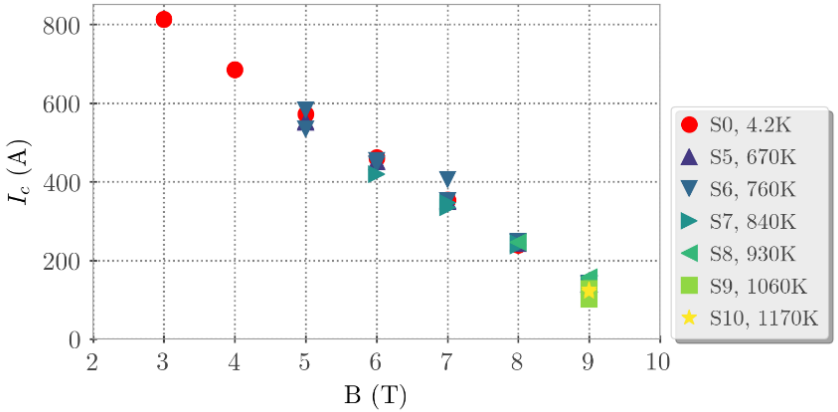
- Hadronic showers cause increased heating with increased penetration depth
- Samples placed in steps of ~100 K (hot spot temperature)
- Thermal stresses due to expansion, thermal gradients in the strands and impact of sample holder expansion on strands cause degradation of sc. properties
- Removal of samples & optical inspection performed at CERN
- Critical current measurements ongoing at Uni-GE

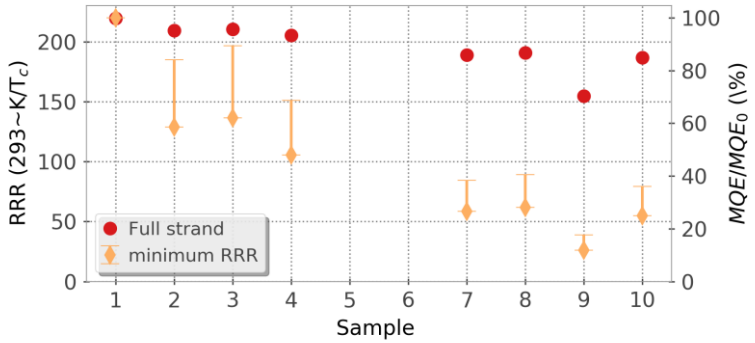




I_c in Nb-Ti strands after beam impact

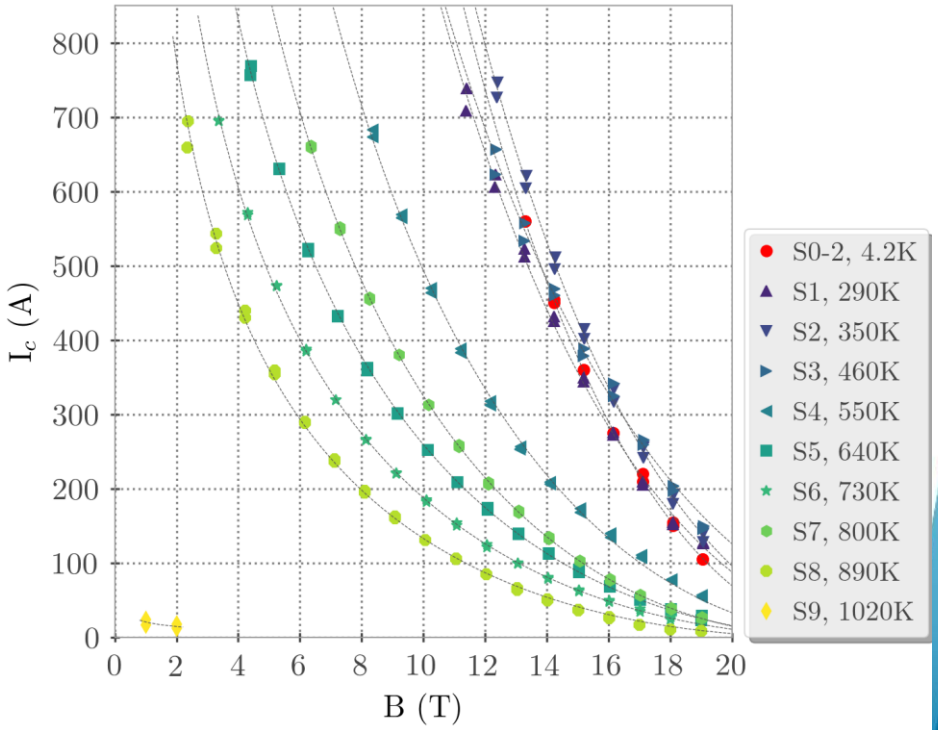
- No degradation of I_c observed
- I_c measurements increasingly difficult at lower fields with increasing hot spot temperature
  - Indicating issues with thermal stability of strands
- Measurements indicate significant reduction of RRR at beam impact position → reduced minimum quench energy (MQE)
  - MQE significantly reduced for samples with hot spots > 800 K





I_c in Nb_3Sn strands after beam impact

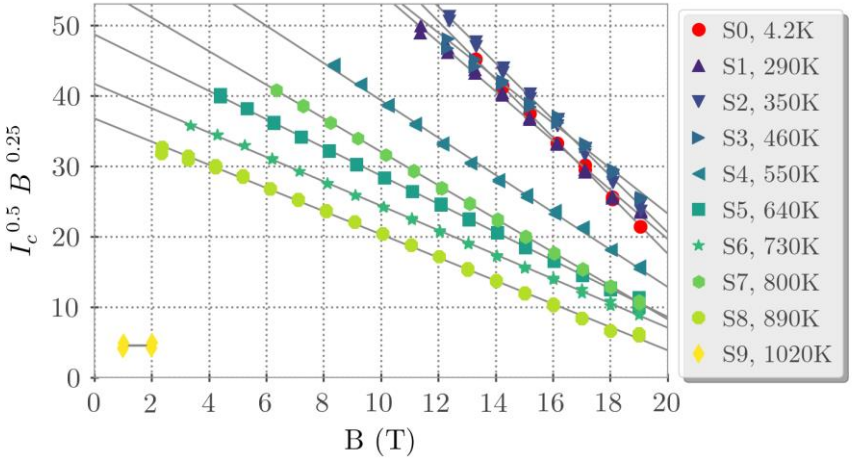
- Significant I_c degradation for hot spots > 460 K
- No measurable transport current for hot spots > 890K → samples destroyed

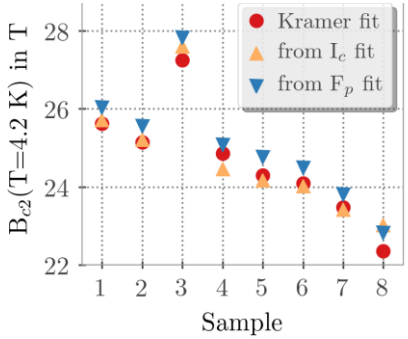


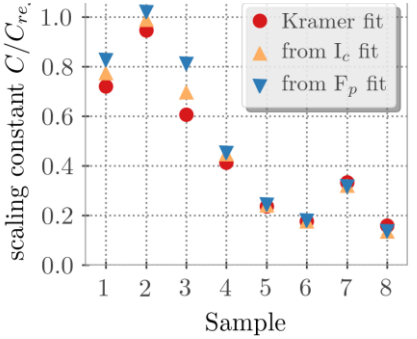
B_{c2} of Nb_3Sn strands after beam impact

Kramer fit:

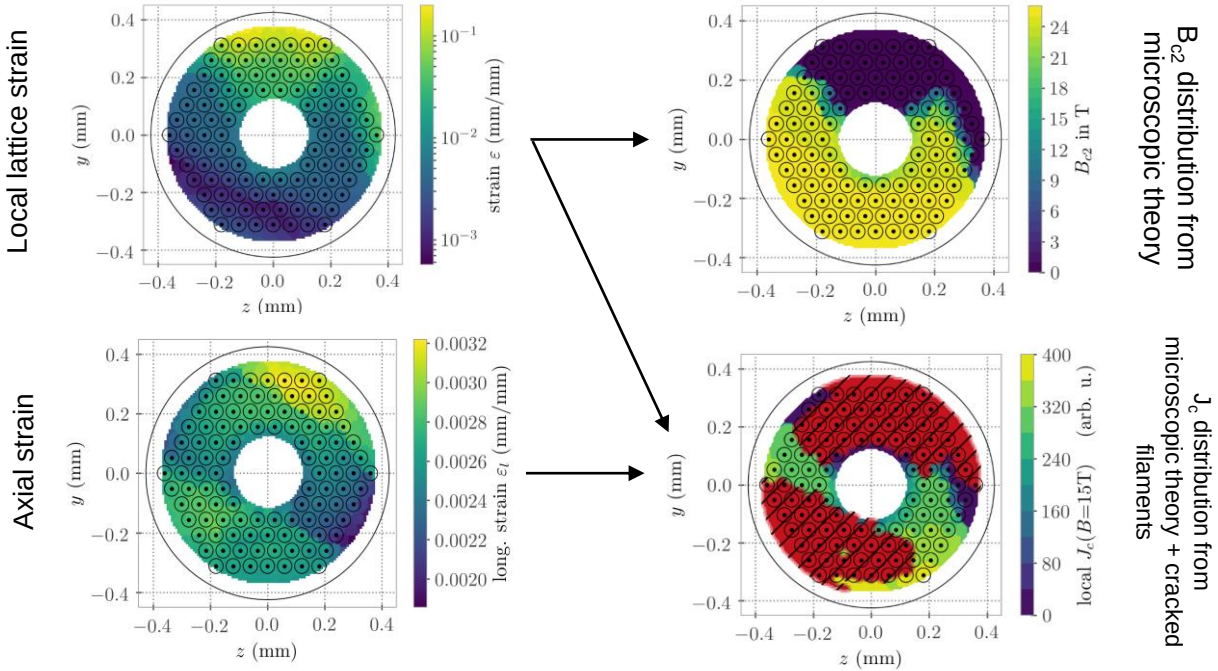
- B_{c2} degrades with increasing hotspot temperatures due to plastic deformation of copper matrix
  - B_{c2} remains > 22 T for samples S1-S8
- I_c degradation dominated by reduction of effective cross section due to filament breakage







Results of thermo-mechanical simulations

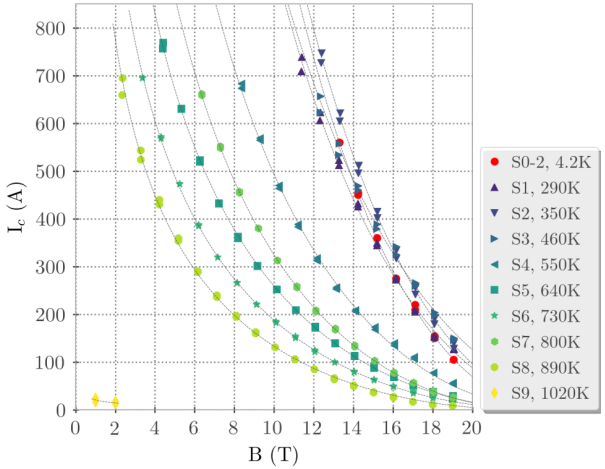


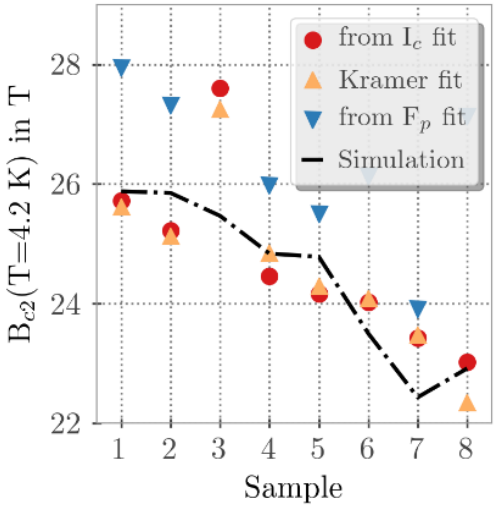
Thermo mechanical simulations performed with ANSYS to

- study the stresses within the strand cross-section due to thermal gradients and expansion
- study the interaction of the strands with the sample holder
- B_{c2} degradation dominated by lattice strain
- J_c degradation combination of lattice & axial strain

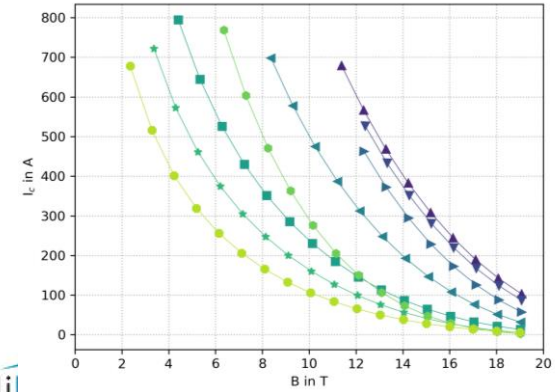
I_c simulations for Nb_3Sn

Measured I_c





Simulated I_c



- Measured I_c and B_{c2} degradations well reproduced in the simulations
- Improved performance of S1-3 (as compared to reference) cannot be explained by simulations

Conclusions & Outlook

- Beam induced damage experiment performed with Nb-Ti, Nb_3Sn strands and YBCO tapes @ 4.2 K reaching hot spot temperatures of up to 1200 K
- Nb-Ti
  - no I_c degradation observed
  - Reduced thermal stability of strands (MQE)
- Nb_3Sn
  - Significant I_c degradation for hot spots > 460 K
  - B_{c2} degradation observed in all samples
  - Sources identified with the help of thermo-mechanical simulations
    - Filament breaking due to too high axial strain → dominating factor for I_c degradation
    - Residual strain from copper matrix and other copper/ bronze phases → B_{c2} degradation & small I_c degradation
- Microscopic analysis and tomography for most damaged Nb_3Sn strands planned to verify model of filament breakage
- YBCO tapes to be measured and compared to simulations