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Deduction of steady-state cable quench limits for various electrical insulation schemes with application to LHC and HL-LHC magnets

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Introduction

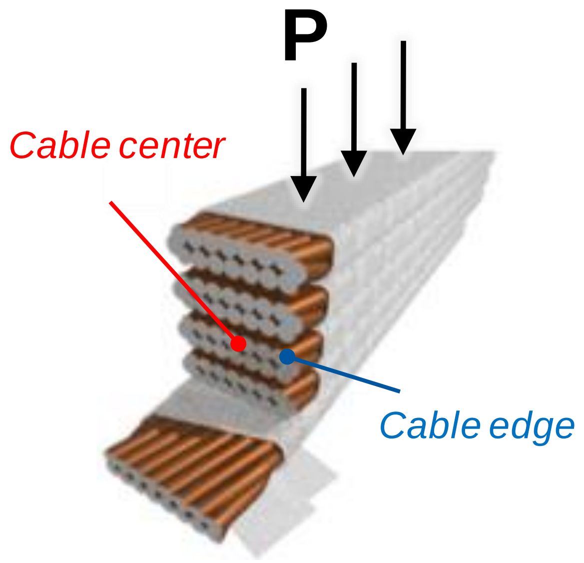
- Preventing beam induced quenches requires an accurate knowledge of the quench limits
  - Especially important for future LHC exploitation at 6.5 – 7 TeV
- Comprehension of quench limits is also important for design of future SC magnets, as those for High Luminosity and High Energy LHC
- The mechanisms determining magtnets stability strongly depend on the beam loss time scale
- We describe how to deduce quench limits from heat transfer measurements of stack of cables
  - can be used to set thresholds for the Beam Loss Monitors
- Outline
  - Experimental technique
  - Heat transfer through cable electrical insulation
  - Deduction of quench limits: method
  - Quench limits of LHC main dipole and HL-LHC interaction regions quadrupole

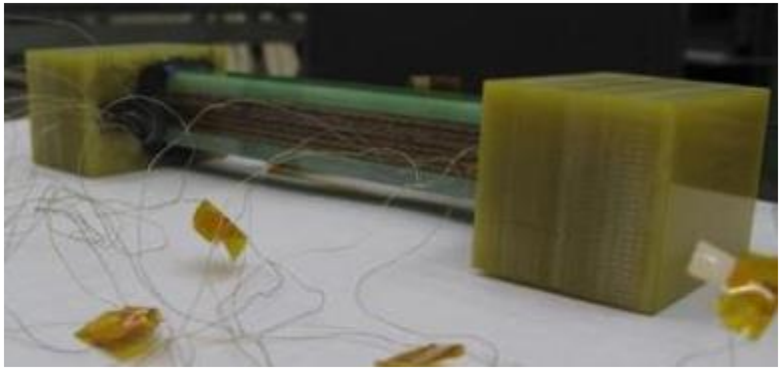
Experimental technique

- The most widespread method to thermally characterize SC coils is the so-called *stack method*

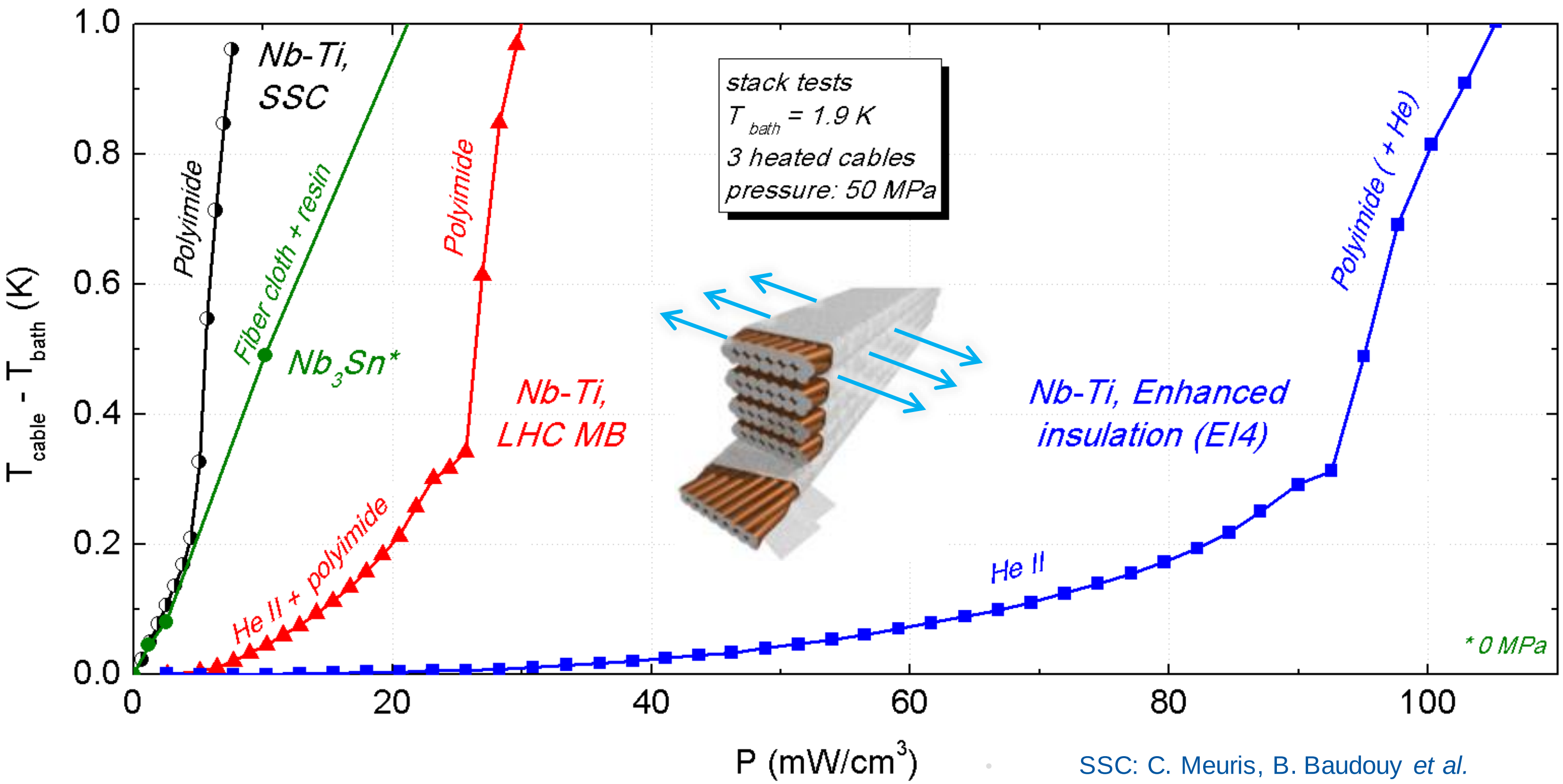
- It allows to measure the heat transfer through the cable's electrical insulation
  - most severe barrier for heat extraction from the magnet

- Measure heat extracted as a function of the cable temperature
  - Under a controlled pressure



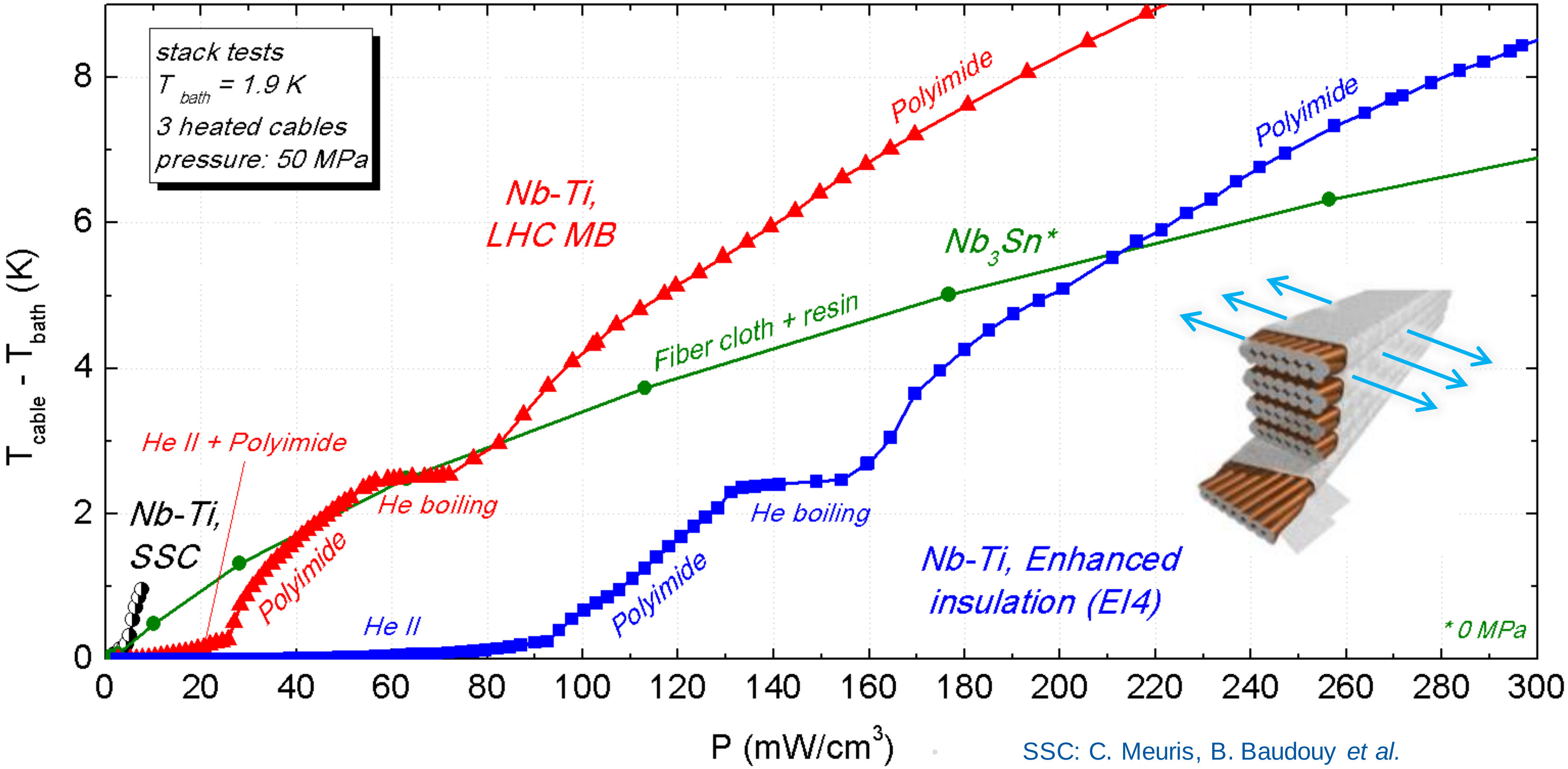


Heat transfer through cable electrical insulation



- SSC: C. Meuris, B. Baudouy *et al.*
- LHC MB and EI4: D. Richter, P.P. Granieri *et al.*
- NB3Sn: P.P. Granieri *et al.*

Heat transfer through cable electrical insulation



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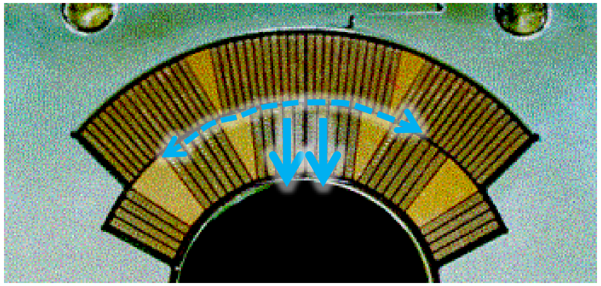
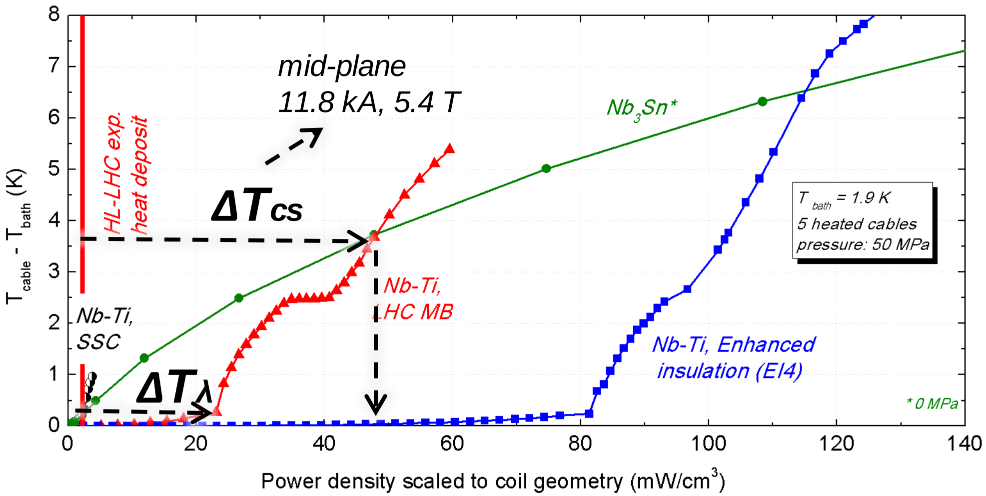
Deduction of cable steady-state quench limits

- For steady-state beam losses, a quench occurs if T_{cable} exceeds T_{cs} (~ 4 K for Nb-Ti, ~ 7 K for Nb_3Sn in a 1.9 K bath)
  - not T_λ, which is a design limit for Nb-Ti coils



- The cable quench limits depend on :
  - Heat extraction:
    - Cable cooling within the magnet
    - Mechanical pressure, if Nb-Ti coil
    - Stack heating configuration
  - Operating conditions:
    - Transport current
    - Magnetic field, thus cable and strand considered

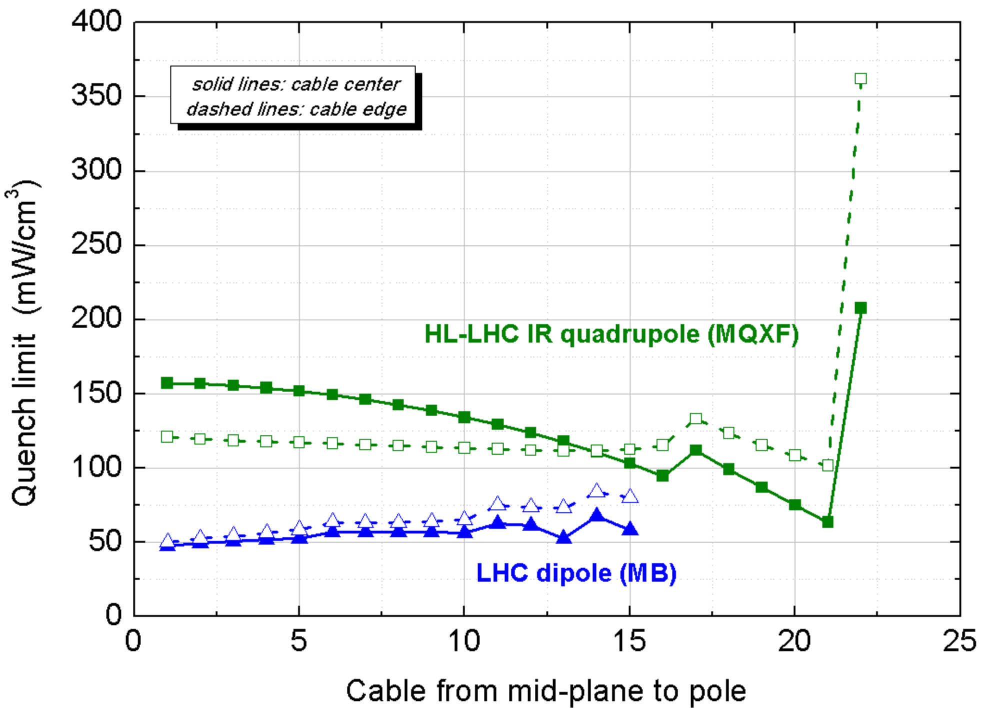


Deduction of cable steady-state quench limits: the method

- 1) experimentally correlate heat extraction and strands temperature
  - Heating configuration of the cables: typically heating all the cables
  - As a function of the mechanical pressure (for He II porous Nb-Ti coils)
  - In different positions of the cable (center vs. edge)
- 2) scale the heat extraction to the coil geometry
  - Only the innermost cables' small face is in direct contact with the He II bath
  - The outermost small face can be, depending on the magnet design, in contact with He
- 3) compute *Tcs (Iop, B)*
  - Cable location within the coil cross-section
  - Strand location within the cable cross-section
- 4) compute the heat extracted at *Tcs (Iop, B)*
  - At the pressure corresponding to the cable location within the coil cross-section
    - LHC dipole (MB): pressure varying btw 50 MPa (mid-plane) to 5 MPa (pole)
    - HL-LHC IR quad (MQXC): pressure varying btw 120 MPa (mid-plane) to 25 MPa (pole)
    - HL-LHC IR quad (MQXF): no pressure

Results

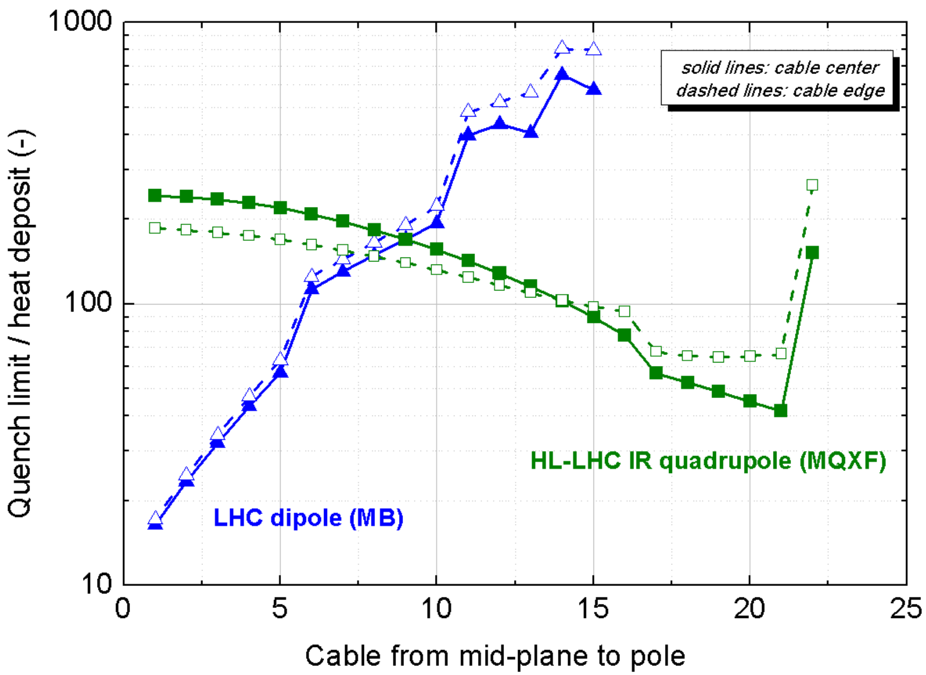
- T_{bath} = 1.9 K, held constant during heat removal
- The deduced quench limits refer to an average heat deposit over the cable
- Quench limit along the azimuthal direction:



MQXF

Results

- Quench limit / heat deposit along the azimuthal direction
  - to determine the most critical cables
  - for both magnets the most heated cables have unluckily the smallest quench limit

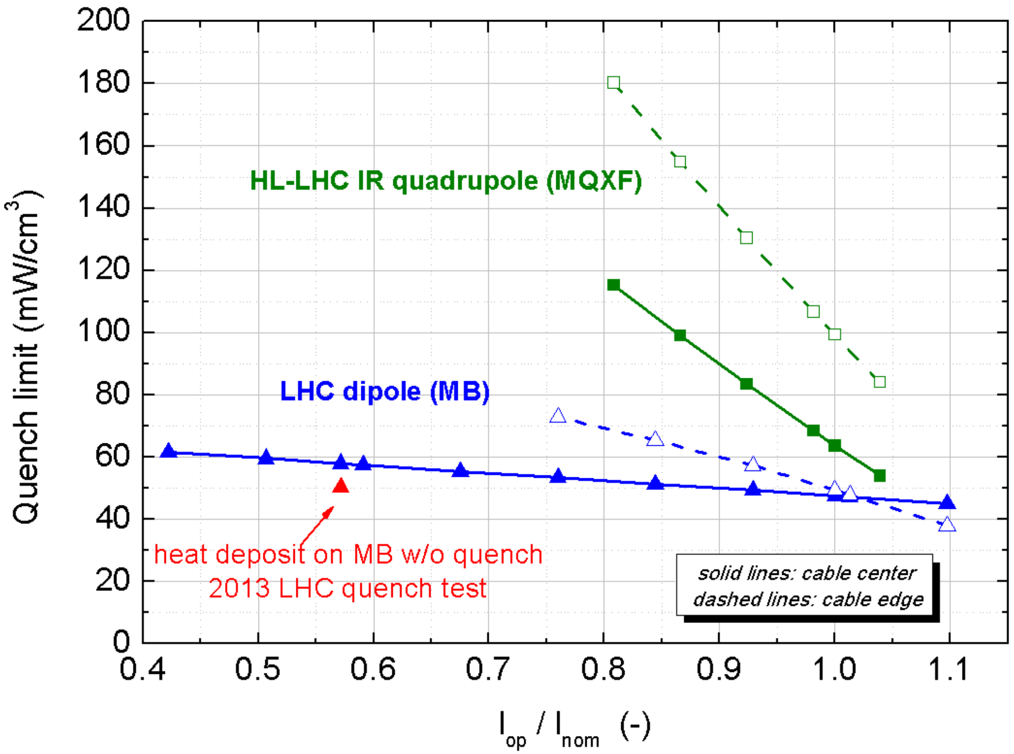


MQXF

Heat deposit data provided by L.S. Esposito, L. Skordis, F. Cerutti

Results

- Quench limit as a function of the transport current
  - in the most critical regions, i.e. mid-plane for MB and close to the pole for MQXF



LHC quench test data provided by S. Redaelli, L. Skordis *et al.*

LHC collimation Review 2013: [*http://indico.cern.ch/conferenceOtherViews.py?view=standard&confId=251588*](http://indico.cern.ch/conferenceOtherViews.py?view=standard&confId=251588)

Conclusion

- By measuring heat transfer on cable stacks, while taking into account the cable cooling within the magnet, one can determine the quench limits

- We presented a general method to determine steady-state cable quench limits, based upon the cooling geometry, the coil mechanical and operating conditions

- The method has been successfully applied to LHC magnets and to magnets foreseen for the High Luminosity upgrade