

# Minimum Quench Energy Analysis of ITER NbTi and Nb<sub>3</sub>Sn CICCs

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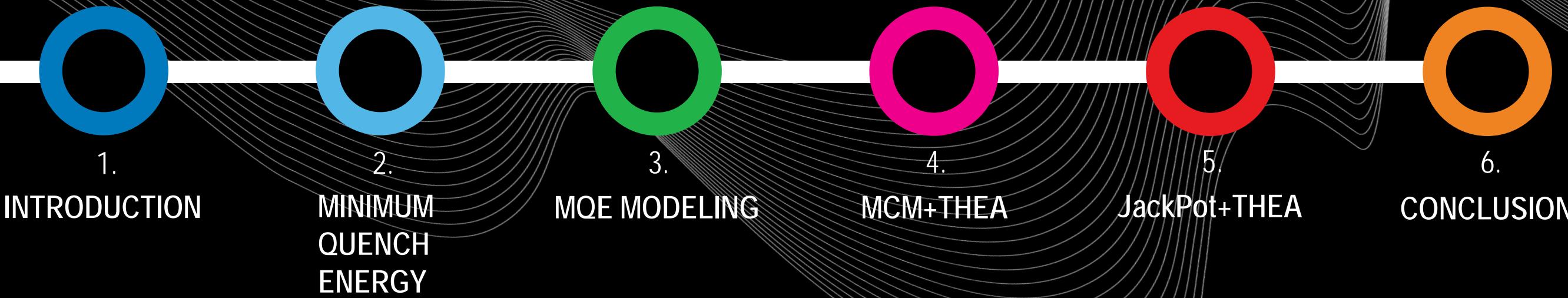
# MT 25

25<sup>th</sup> International Conference  
on Magnet Technology

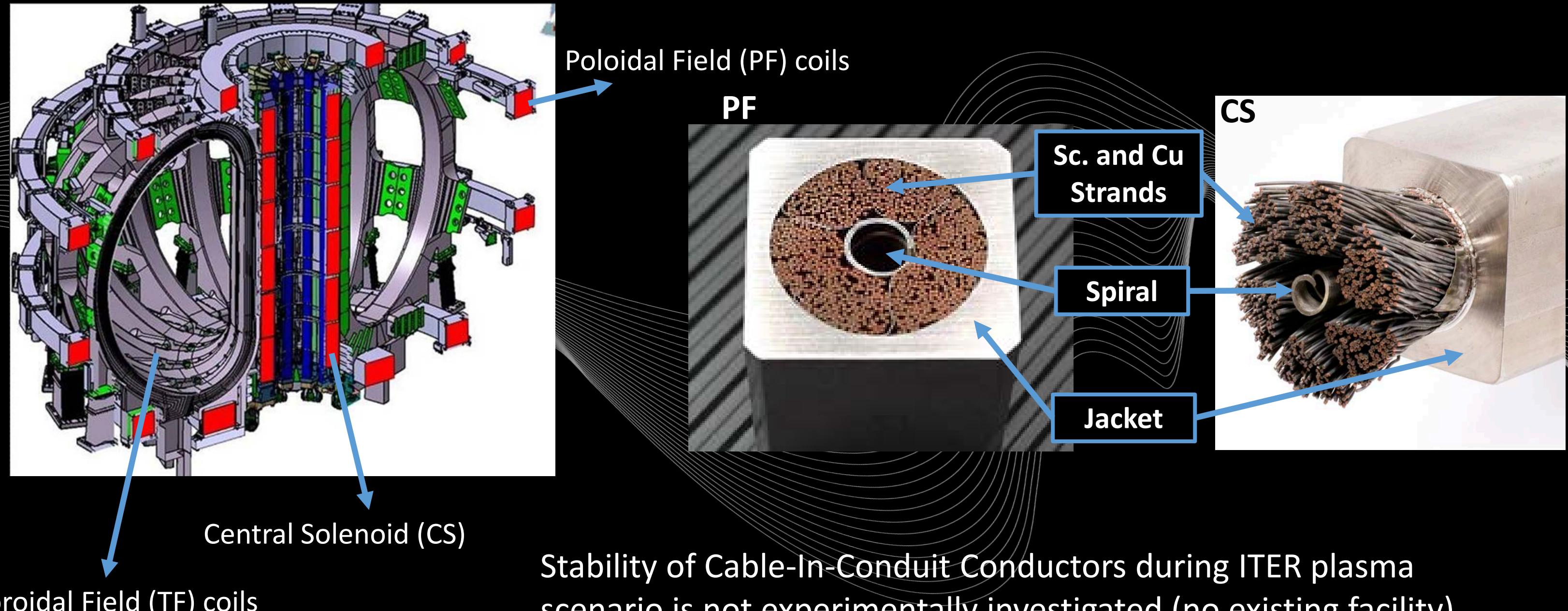


Amsterdam, August 27 - September 1, 2017

# IN THIS PRESENTATION:

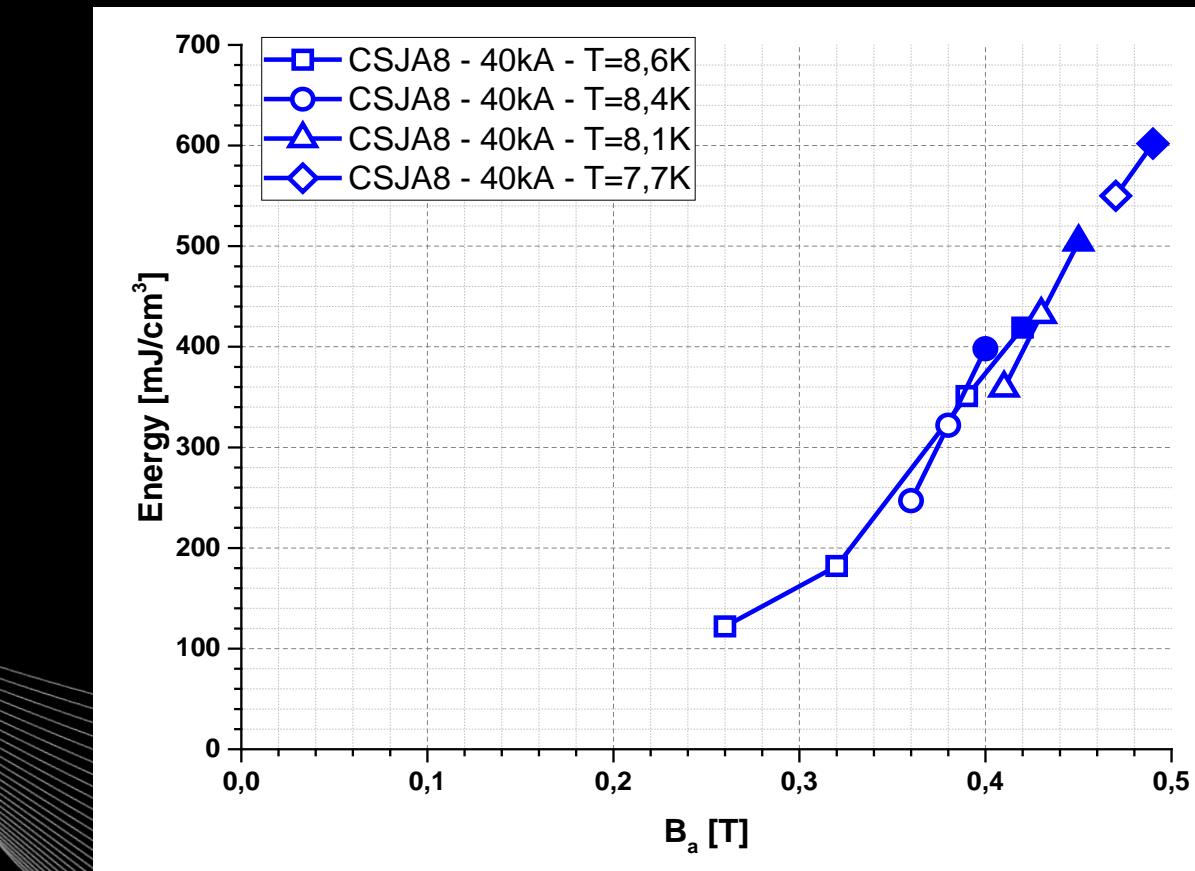
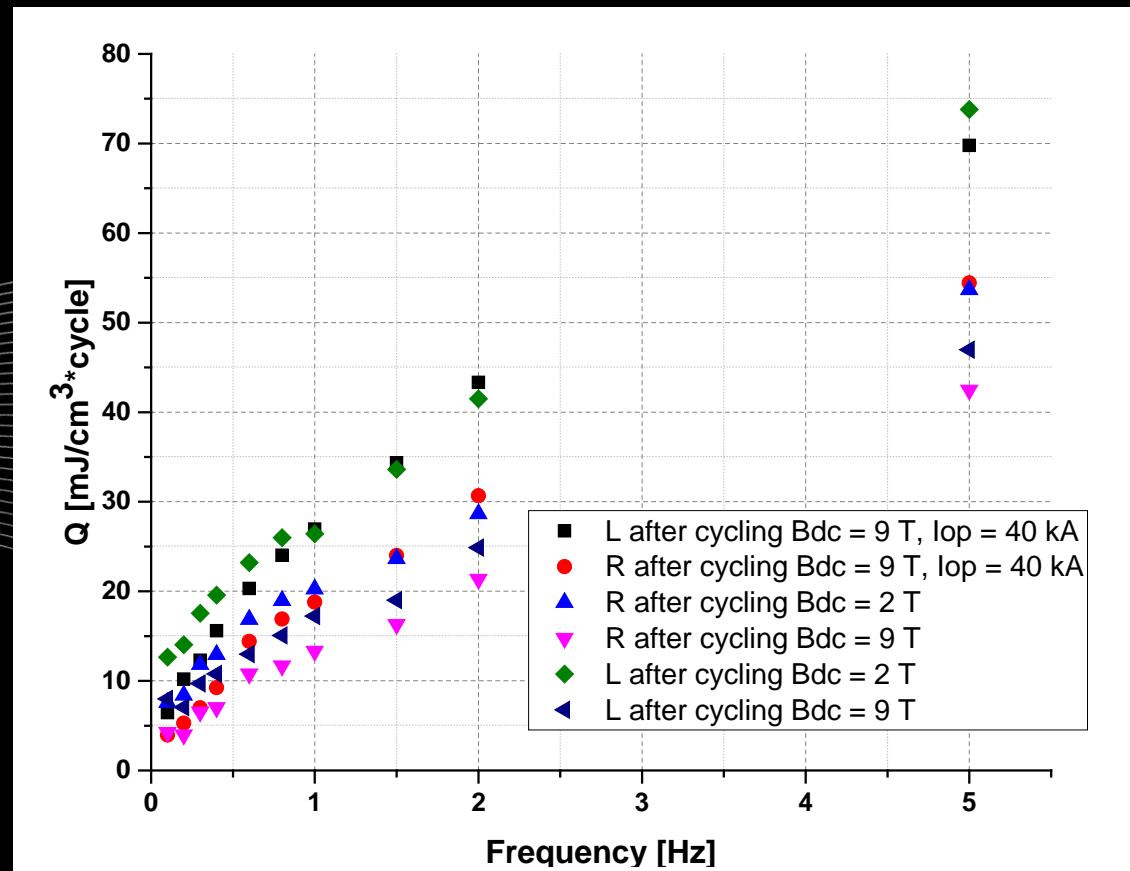


# INTRODUCTION

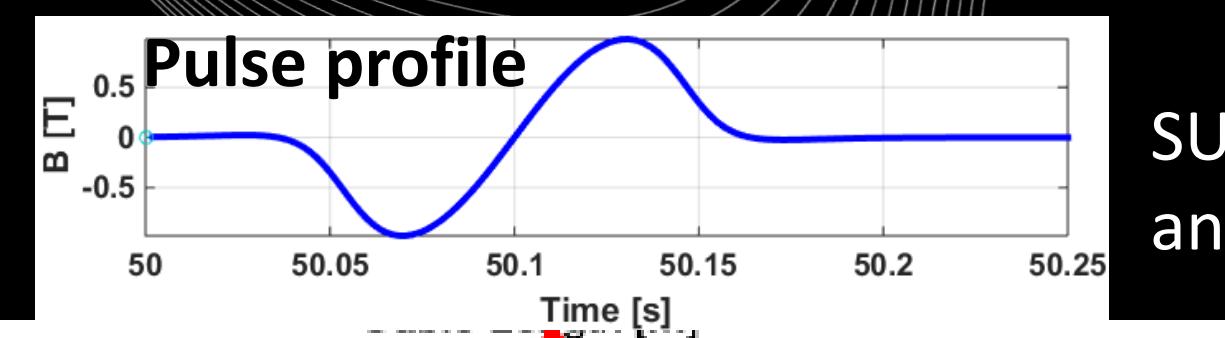


Stability of Cable-In-Conduit Conductors during ITER plasma scenario is not experimentally investigated (no existing facility). Simulations can give predicted performance of CICCs stability during fast magnetic field transients.

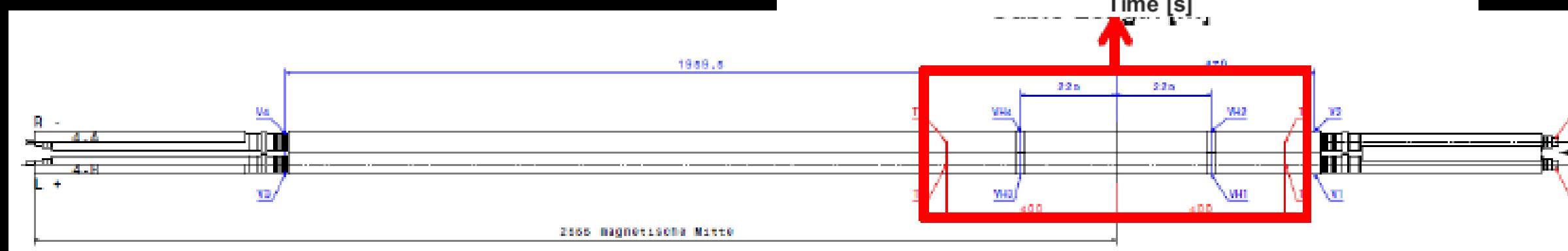
# MINIMUM QUENCH ENERGY



CSJA8 AC loss measured in SULTAN facility



SULTAN short sample and AC field profile



# MODELING - MCM (1)

Multi-Constant-Model

1 time constant for each cabling stage of CICCs.

$$P_{tot}(B) = \sum_i \frac{K_i \tau_i \left( \frac{dB_i}{dt} \right)^2}{\mu_0}$$

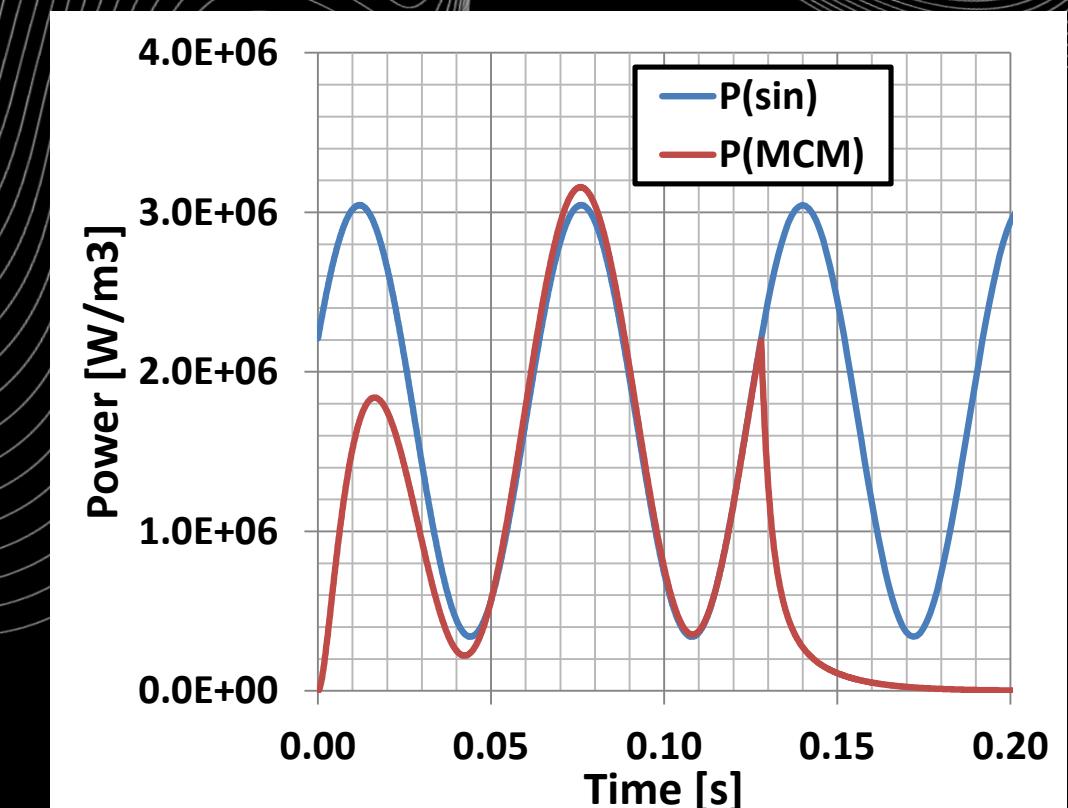
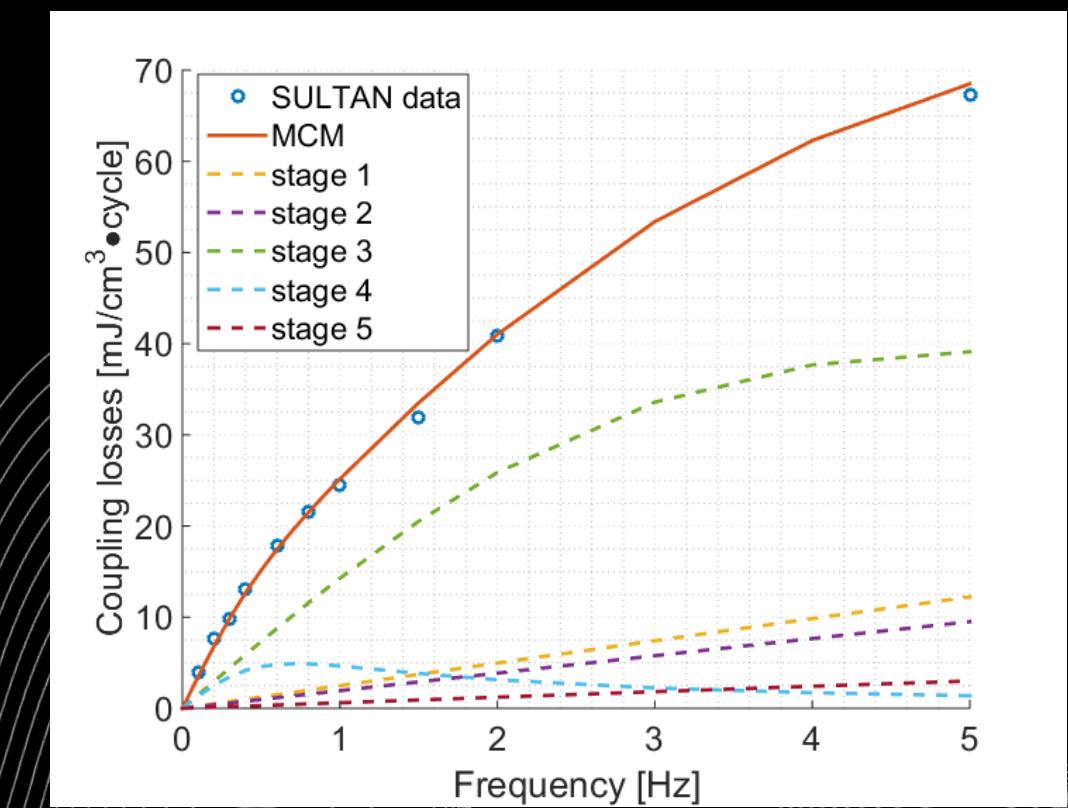
The power calculation depends only on the magnetic field, effects of temperature and current are neglected.

The  $K_i$  and  $\tau_i$  values are extracted from the coupling loss experimental data.

Truncated Sinusoid

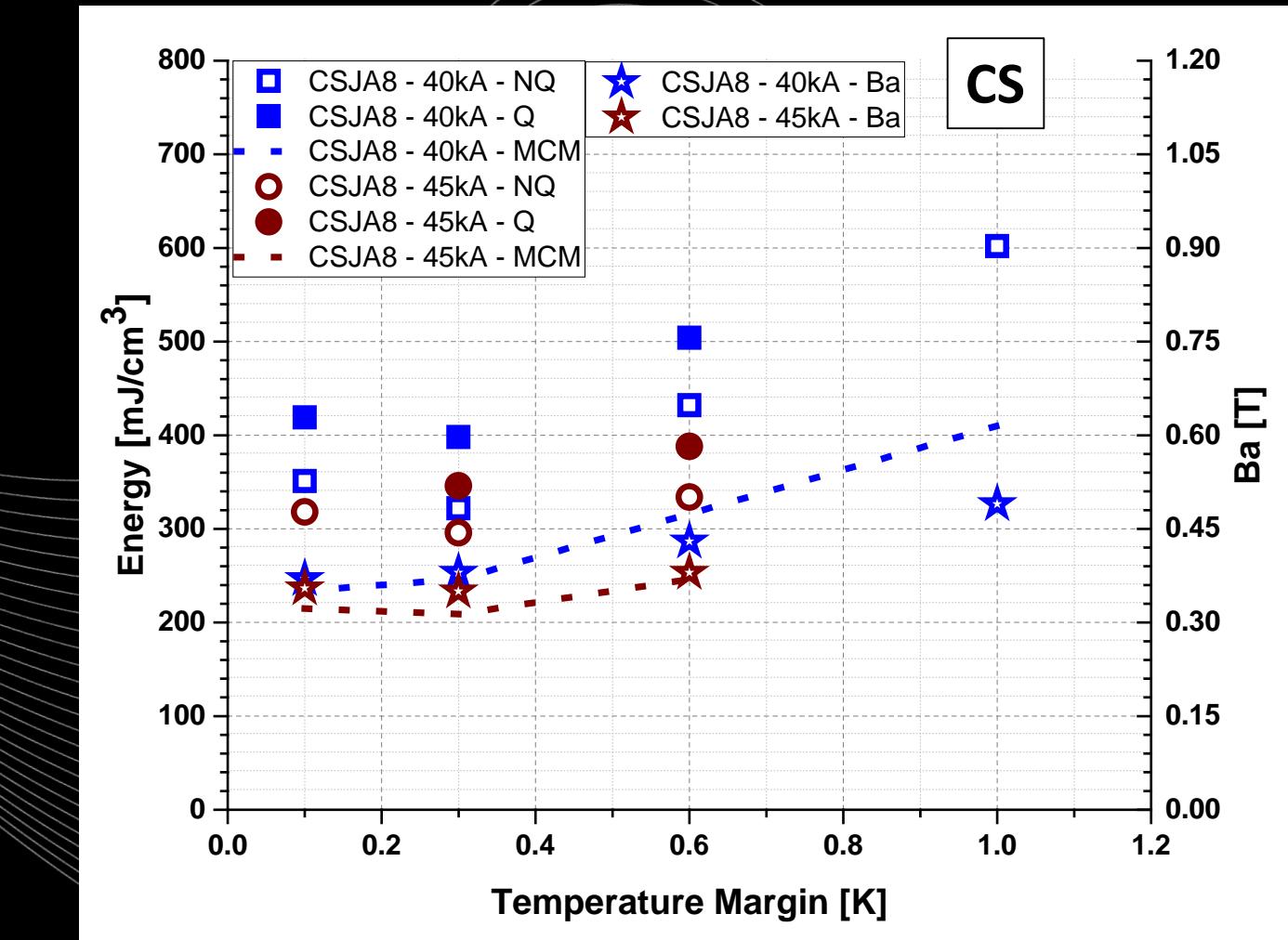
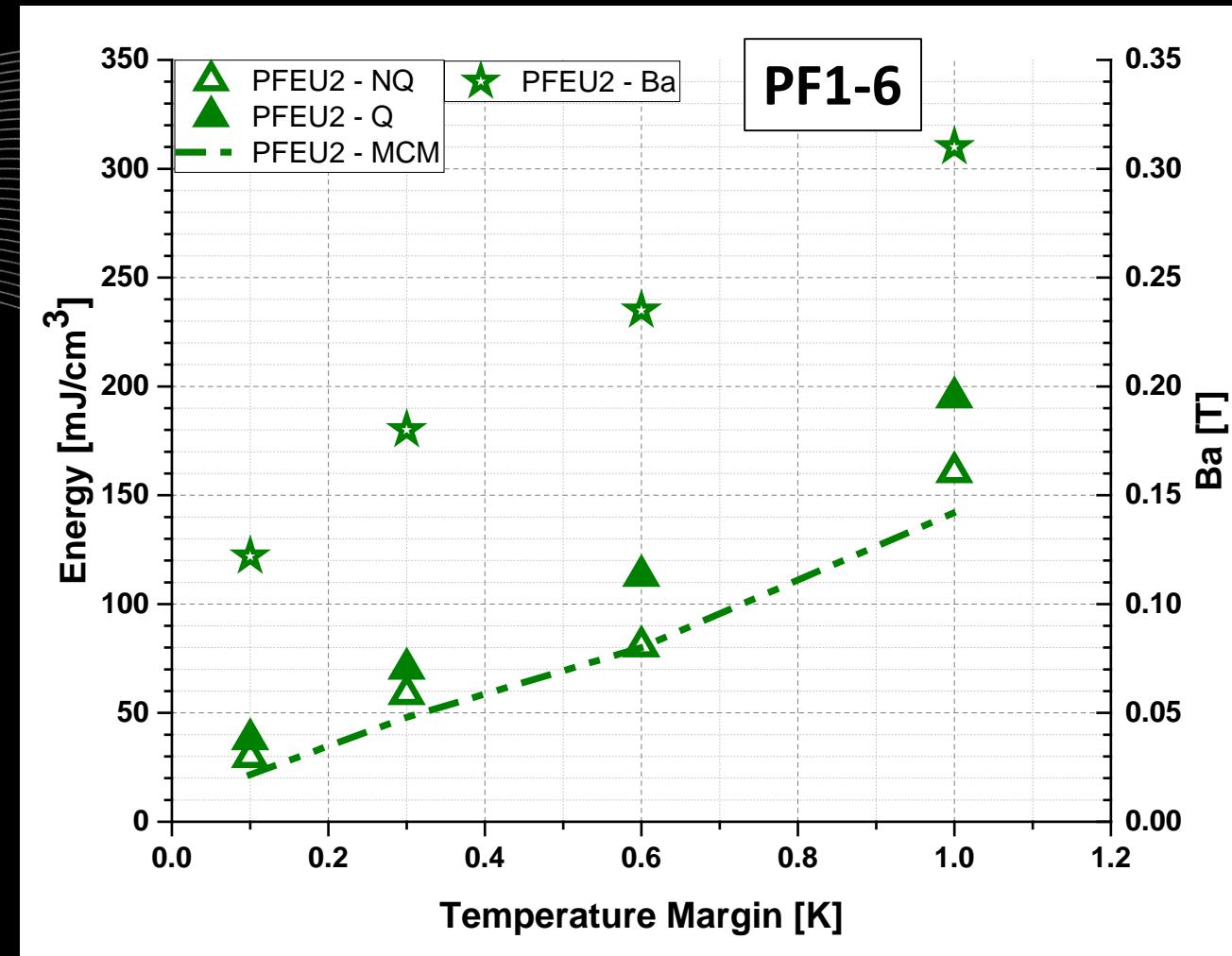
$$B_{iI} = \frac{B_m}{\sqrt{\omega^2 \tau^2 + 1}} \left[ \sin(\delta) e^{-\frac{t}{\tau}} + \sin(\omega t - \delta) \right] \quad \text{for } 0 < t < T$$

$$B_{iII} = \frac{B_m}{\sqrt{\omega^2 \tau^2 + 1}} \sin(\delta) \left( 1 - e^{-\frac{T}{\tau}} \right) e^{-\frac{t}{\tau}} \quad \text{for } t > T$$



# MODELING - MCM (2)

**MQE tests** are performed at **higher temperature** and **magnetic field** amplitude, than AC loss tests.  
MCM is not necessarily able to reproduce MQE tests without adding corrections.

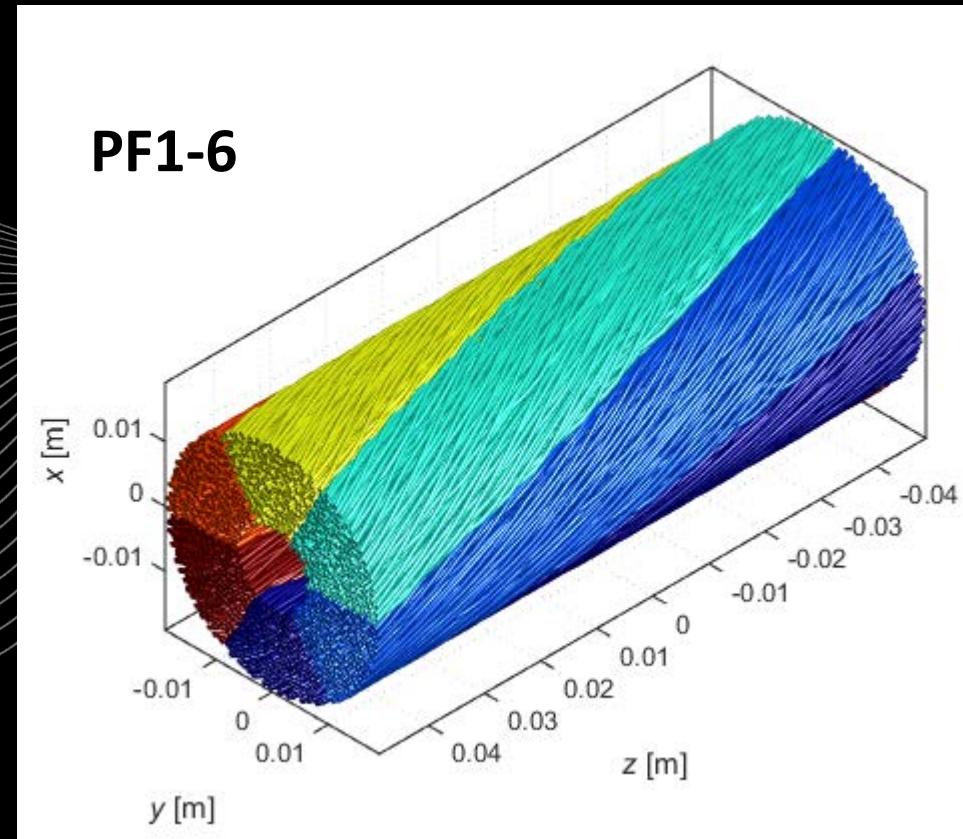
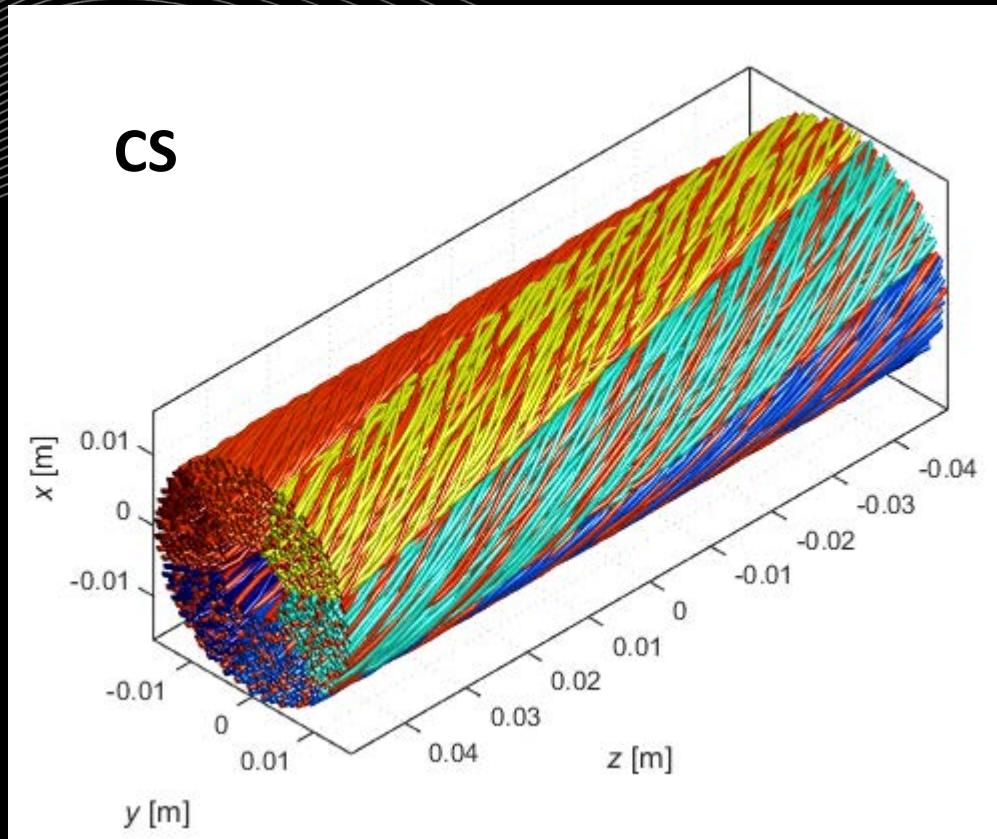


MCM is able to reproduce PF1-6 conductor  
MQE without correction.

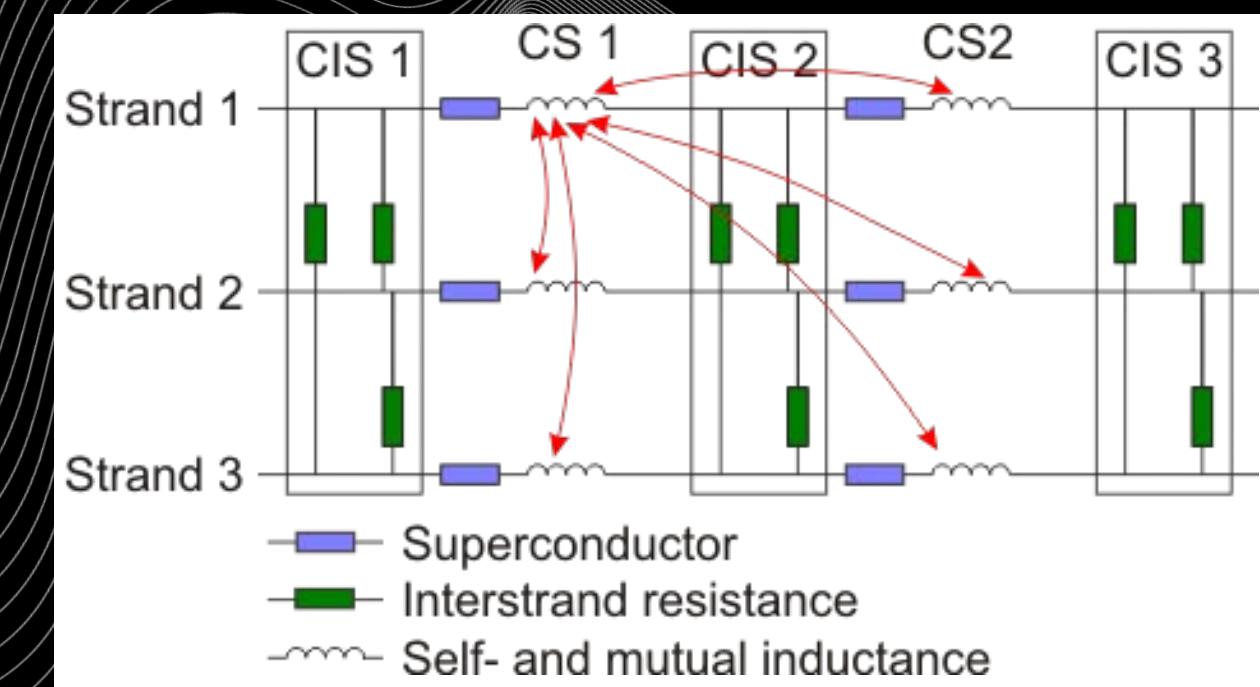
MCM is rescaled to match Nb<sub>3</sub>Sn MQE  
experiment using a constant correction factor.

# MODELING - JACKPOT AC/DC (1)

Cable model accurately describing *all* (>1000) strand trajectories in CICC;  
including compaction steps.



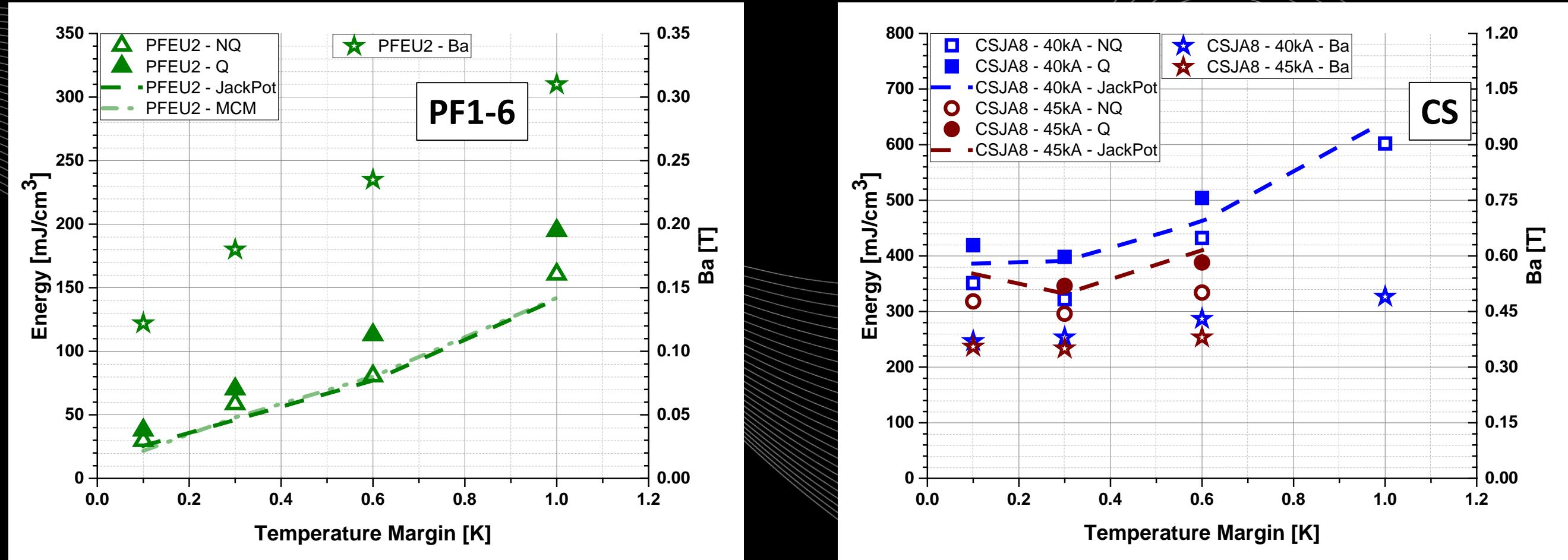
- Inter-strand contact resistance distribution
- strand's mutual inductances
- coupling with self- & background field
- strand's properties scaling law  $I_c(B,T,e)$



The only free parameters are inter-strand and inter-petal contact resistivity.  
The values are determined using SULTAN AC loss tests.

# MODELING - JACKPOT AC/DC (2)

**MQE tests** are performed at **higher temperature** and **magnetic field** amplitude, than AC loss tests.  
JackPot calibration is tested using the MQE tests performed at SULTAN.



JackPot is able to reproduce PF1-6 and CS MQE without any correction since it contains  $I_c(B, T, \varepsilon)$  scaling and inductive coupling.

# MODELING - THEA

Thermal, Hydraulic and Electric Analysis of Superconducting Cables (THEA) is the code used for this study.

THEA is a 1-D model, it computes the evolution of temperature, coolant flow and current distribution during fast transient like stability perturbations.

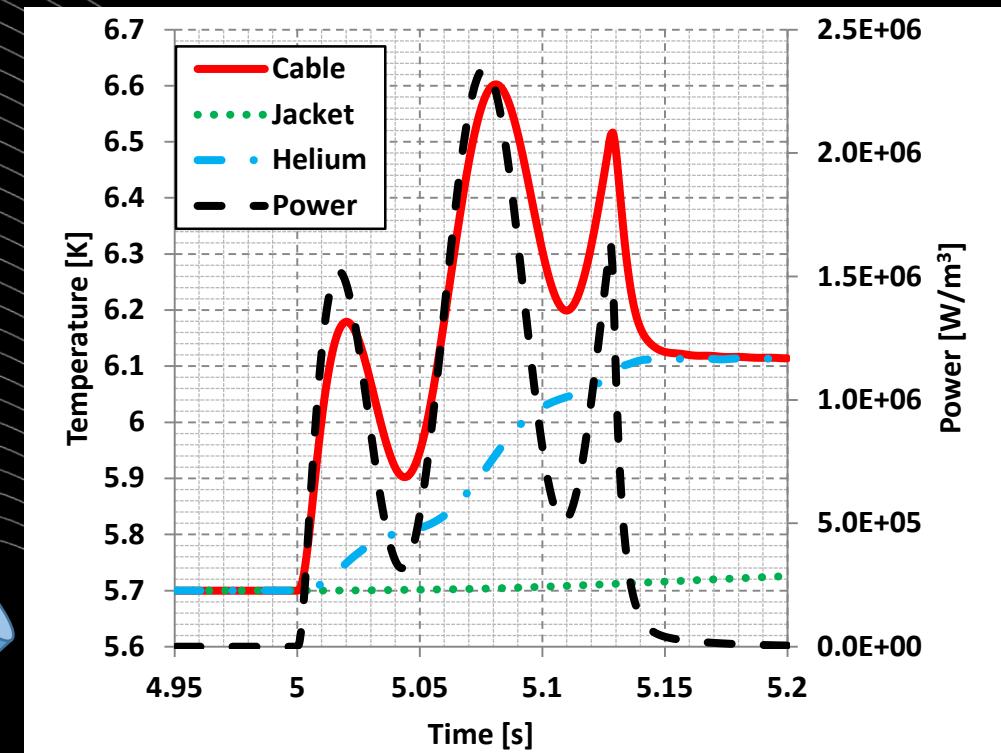
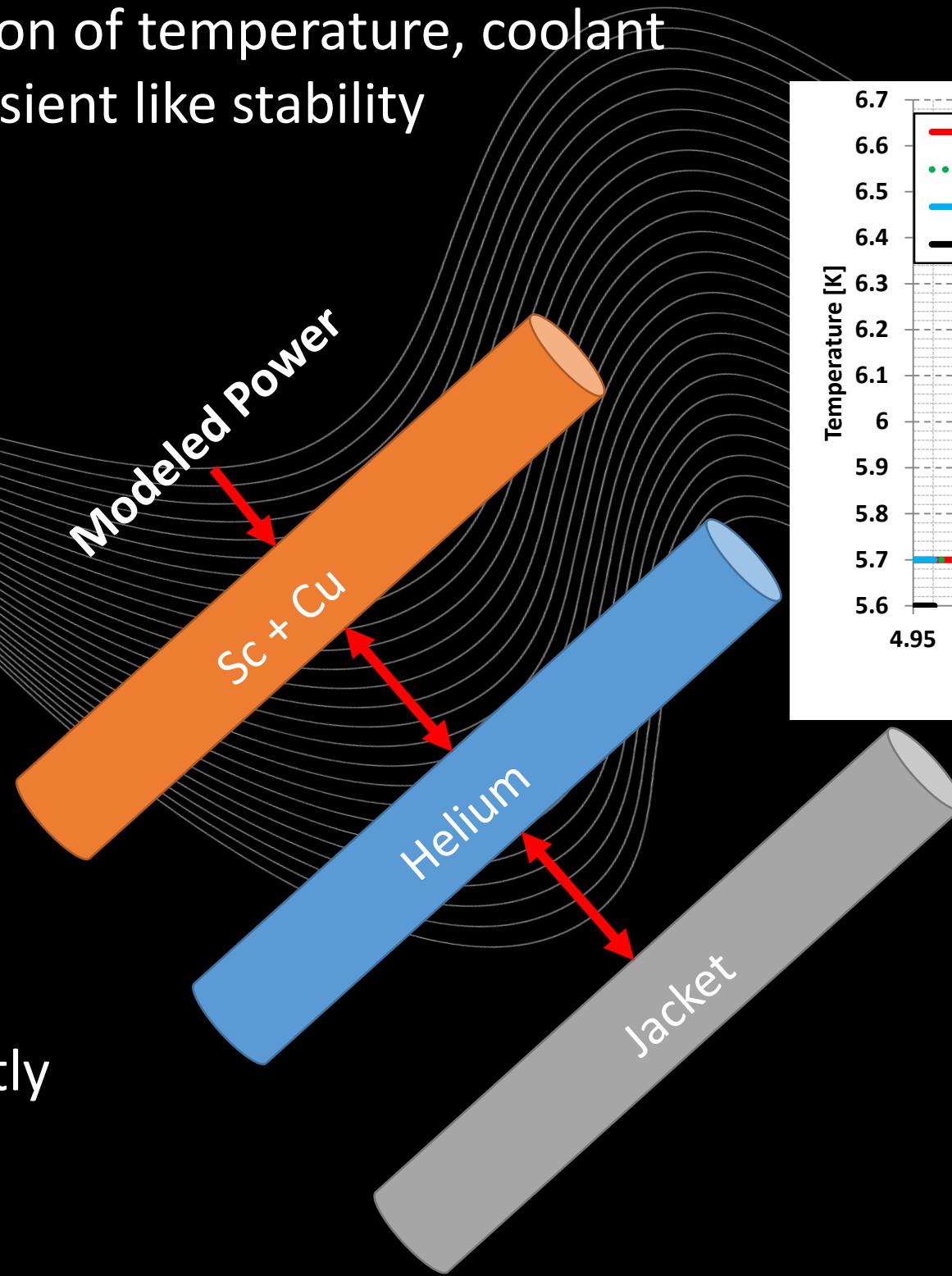
Material components:

- Superconductor ( $\text{NbTi}$  or  $\text{Nb}_3\text{Sn}$ ) + Conductor (Cu)
- Jacket: stain-less steel

Hydraulics:

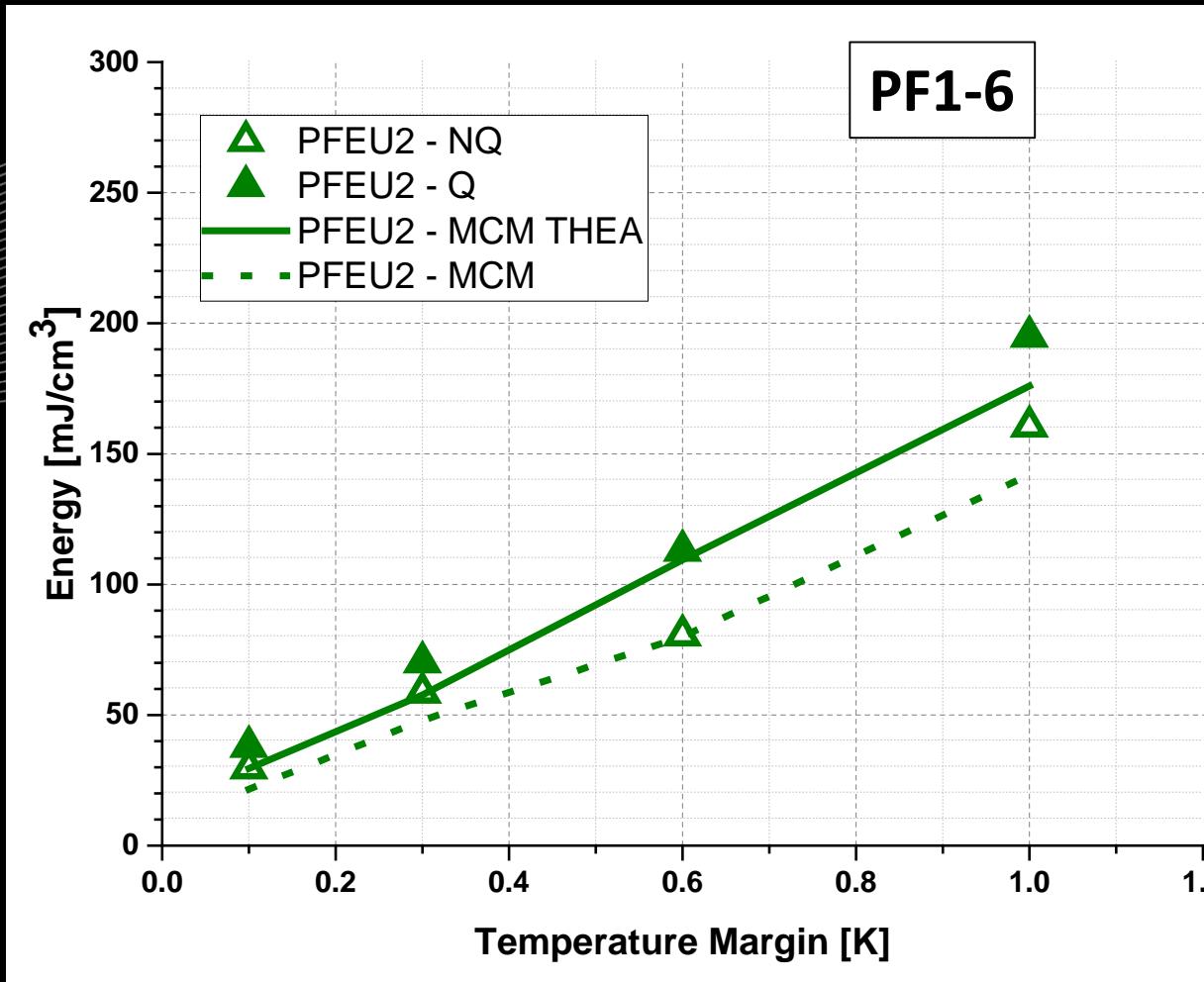
- No Helium channel (Sultan sample)
- Helium only in the bundle
- Friction factor: calibrated with experimental data to reach the experimental mass flow

Power (from MCM or Jackpot) injected directly in the Sc+Cu component

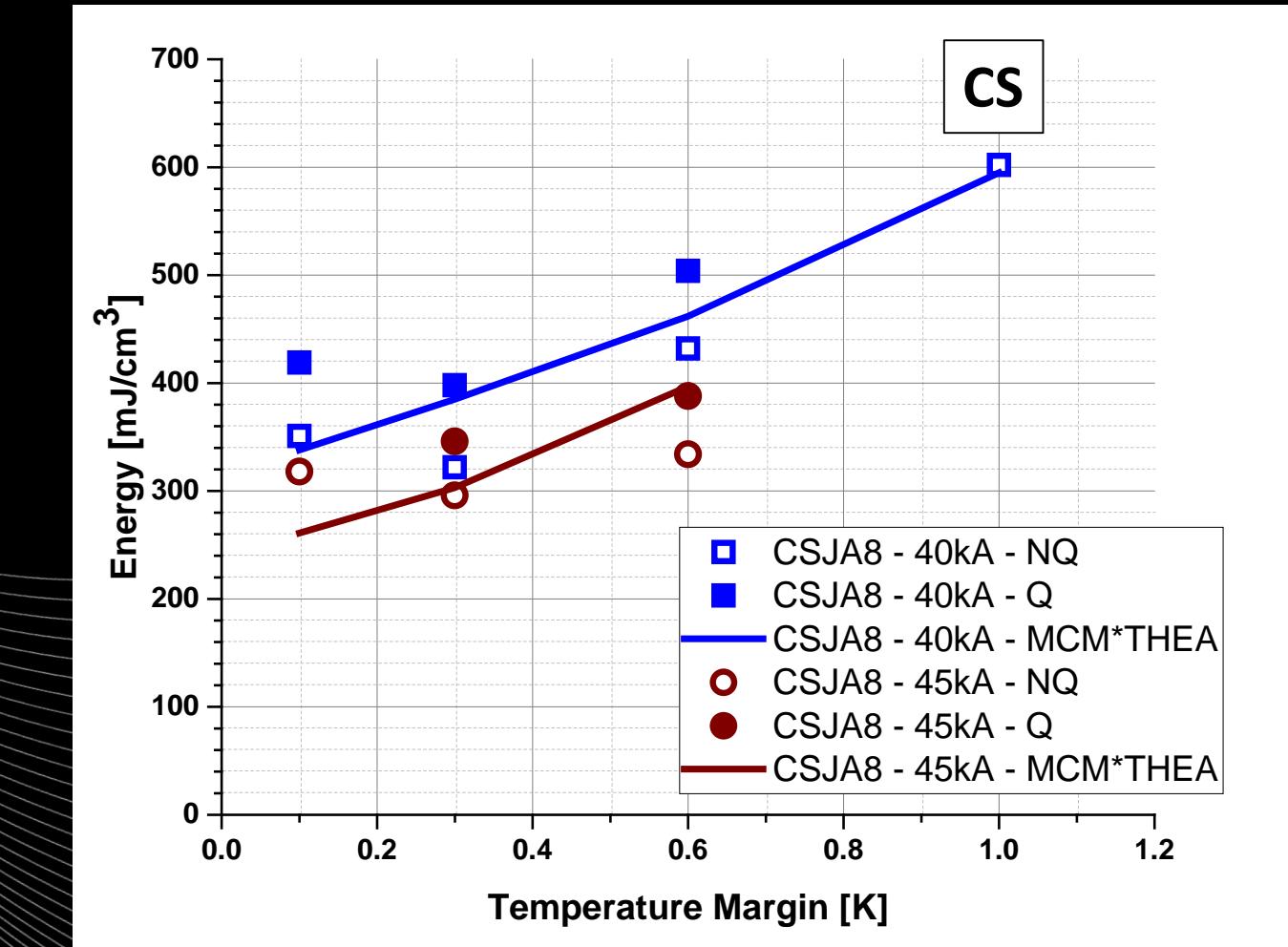


# MCM+THEA

MCM+THEA models the MQE for PF1-6 and CS conductors.



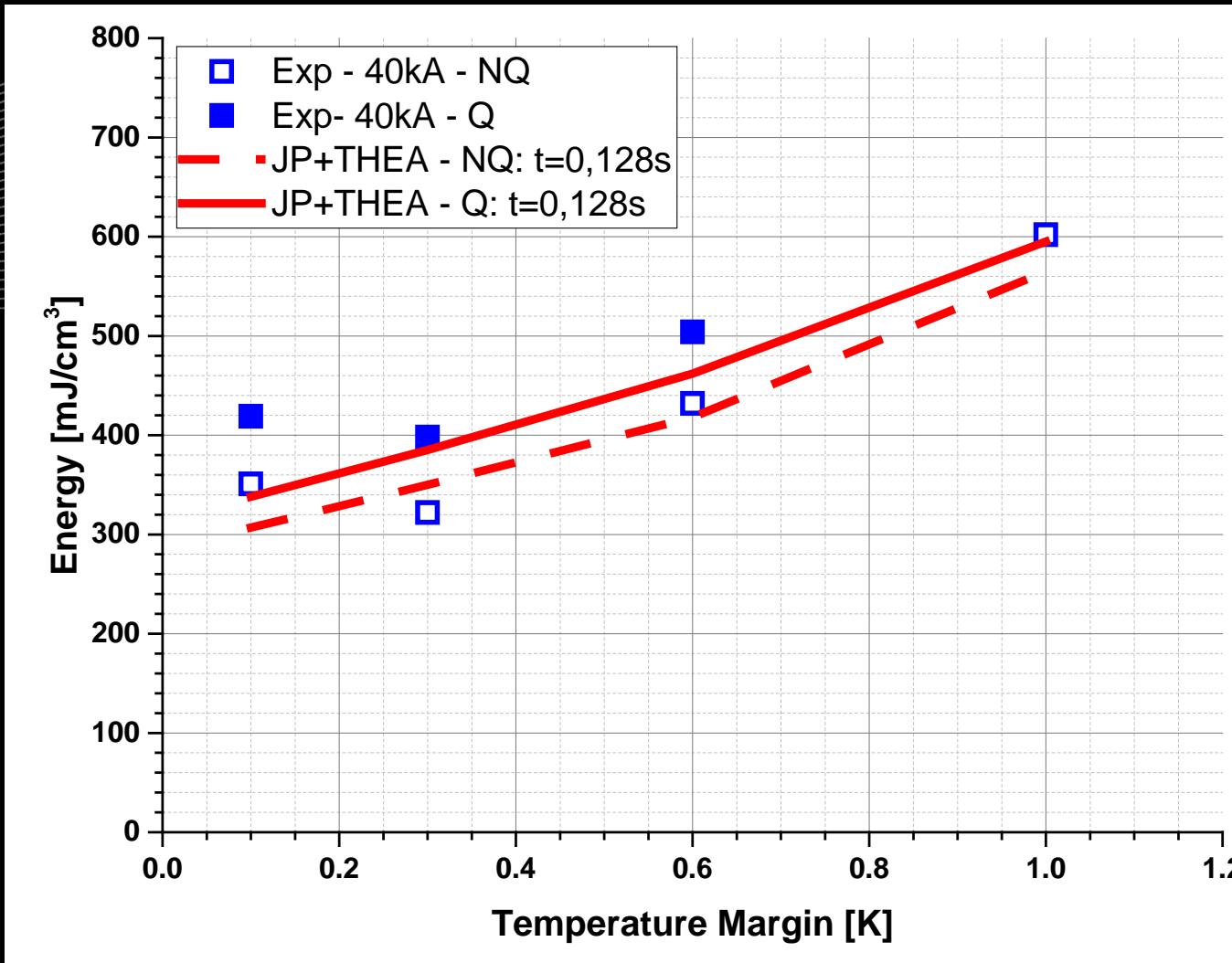
The model of PF1-6 has good agreement with experimental data.



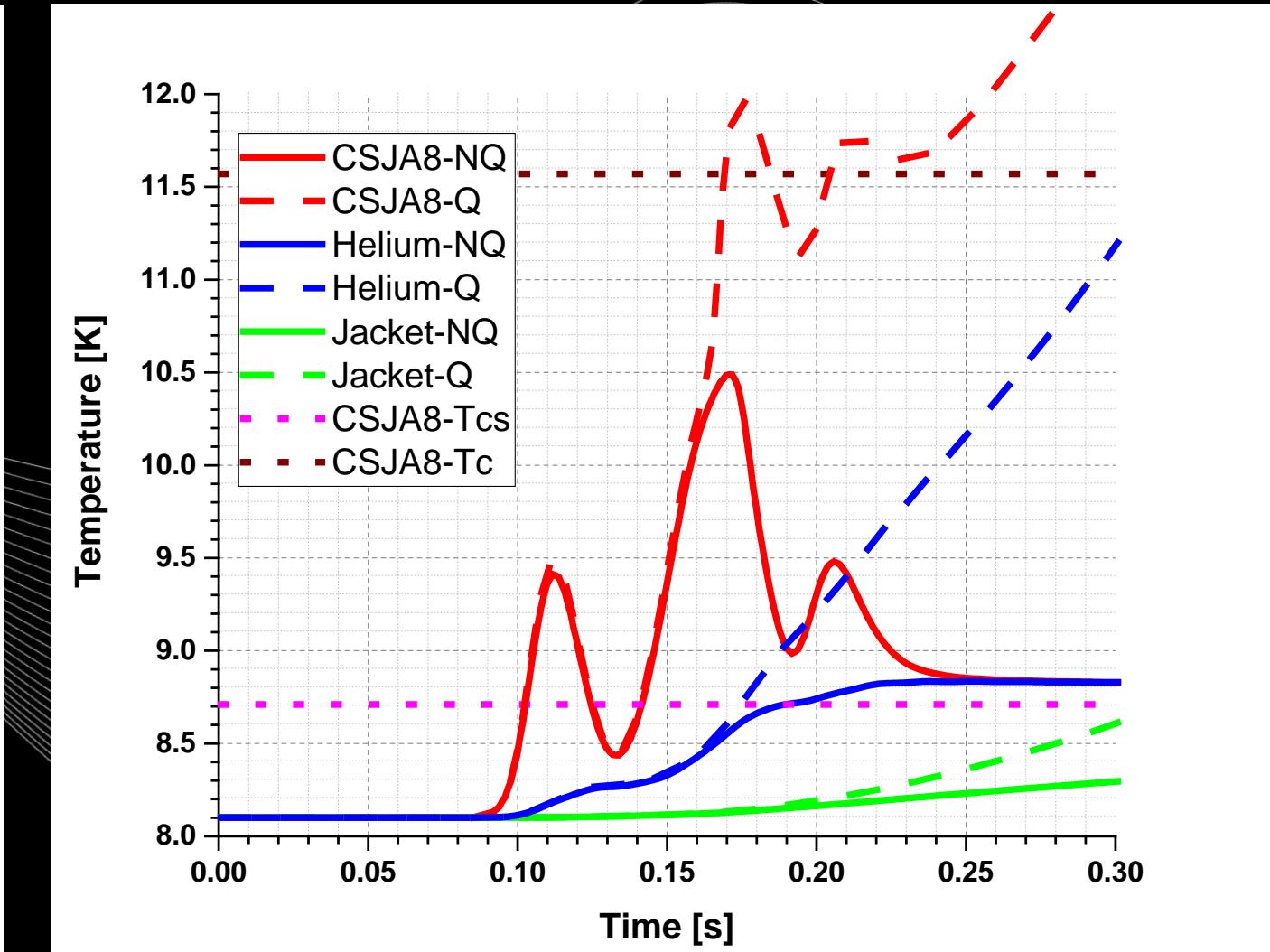
MCM with the correction factor (\*) combined with THEA is able to fit the experimental MQE. It is not possible to define the magnetic field pulse necessary to initiate a quench.

# JACKPOT+THEA

JackPot+THEA requires long simulation time, only CS cable is tested using JackPot+THEA



Good agreement with experimental data, only discrepancy at low temperature margin, probably due to the difficulty in temperature control during the experiment.



Temperature evolution profile in the conductor, in both quench and recover condition

# CONCLUSION

- MCM and JackPot models were compared after combining them with the THEA model for computation of MQE.
- MCM-THEA model combination: it appears that MCM is not capable to precisely predict the amount of power generated during a time varying magnetic field pulse for the Nb<sub>3</sub>Sn CICC.
- The JackPot model is able to calculate accurately the energy deposited in a cable
- The combination JackPot+THEA is able to predict the SULTAN MQE experiment for CSJA8 with excellent agreement. This implies that JackPot+ THEA provides a good basis for stability analyses of ITER coils subjected to severe alternating magnetic fields like at the plasma operating scenario.



# Thank you for your attention



For more information on JackPot+THEA,  
please look for T. Bagni during the Poster Session G3  
30<sup>th</sup> Aug 2017, 13:15